9 Dryland Cropping in the Canadian Prairies and the U.S. Northern Great Plains

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For the purpose of this chapter, the Canadian Prairies and the U.S. northern Great Plains are defined as the area north from the southern borders of Colorado and Kansas (about 37° N lat) to Peace River, (56° N lat) Alberta, Canada and from the Rocky Mountains (104° W long) at the southern boundary and angling to 113° W long in the north) to the eastern borders of Kansas, Nebraska, South Dakota, and North Dakota in the USA (about 95° W long). In Canada, the eastern border angles westward from Winnipeg to Peace River. The Canadian Prairies are located south of the boreal forest, but encompass some of the mixed grass-forest interface. However, the emphasis will be on the drier portion of this area; mainly those areas with <450- mm mean annual precipitation. Native vegetation in the western regions of the northern Great Plains is short grass prairie and shifts to mixed grasses as precipitation increases to the east (Padbury et al., 2002).

Although not part of the northern Great Plains, there will be some discussion about agriculture in the Yukon Territory and interior Alaska because of the climatic similarity of these regions to the Great Plains. They are truly the northern fringes of arable agriculture in North America, and soils and climate offer potential for extensive agricultural expansion (Mills, 1992).

CLIMATE

The climate of both the northern Great Plains of the USA and the Canadian Prairies is typically continental with long cold winters and short warm summers. Annual precipitation in the northern Great Plains is characterized by a large west–east gradient that increases from 300 mm along the western edge to over 800 mm in the southeastern corner (Fig. 9–1) (Cannell and Dregne, 1983). This west–east gradient becomes less pronounced as one goes north because of decreasing precipitation from south to north along the eastern edge of the northern Great Plains. For instance, precipitation increases from 401 mm in Colorado Springs, CO to 968 mm along the eastern border at Olathe, KS, whereas further north Havre, MT receives 289 mm in the west vs. 498 mm in Fargo, ND in the east (Fig. 9–2). A similar pattern exists in Canada with Medicine Hat receiving 323 mm of precipitation compared to 367 and 505 mm of precipitation for Regina and Winnipeg, respectively (Fig. 9–3).

Throughout both the northern Great Plains and Canadian Prairies annual precipitation varies considerably from year to year. The region is also subject to severe thunderstorm activity, especially during July and August. These thunderstorms are frequently of short duration, but may be very intense with the potential to cause extensive soil erosion. They may also contain hail of sufficient size and intensity to severely damage crops. Furthermore, they tend to be scattered with high intensity rainfall occurring in a narrow band, while adjacent areas receive little or no rain.

Unlike precipitation, temperature patterns tend to follow along latitudinal lines with little temperature change from west to east (Fig. 9–2 and 9–3). However, mean annual temperatures are slightly warmer in Havre, MT than in Bismarck or Fargo, ND. Likewise, Medicine Hat has warmer winters than Regina or Winnipeg in Canada. Midsummer mean monthly temperatures are somewhat higher in the south than the north but more importantly, the south has fewer months exhibiting subzero mean monthly lows. Longer periods of cold greatly shorten the growing season in northern locations, which play an important role in restricting crop diversity. However, longer daylength with sufficient light intensity promotes a longer period of net photosynthesis, which to some extent compensates for the shorter growing season. Figure 9–4 illustrates the mean annual frost-free days across the region.

Throughout most of the region, precipitation and temperature patterns favor the growth of cool-season crops, particularly small grains. Peak amounts of precipitation often occur 1 mo before maximum temperatures, which allows good vegetative growth during the cooler part of the growing season. Precipitation then decreases while temperatures remain high and small grains reach maturity (Fig. 9–2 and 9–3). However, differences between the supply of water and the crop's requirement for water can be great and limit production. De Jong and Steppuhn (1983) compared evapotranspiration with precipitation at selected locations in Canada and found that during the growing season evapotranspiration exceeds precipitation (Fig. 9–5a and 9–5b). Although winter precipitation exceeds evapotranspiration, much of it is in the form of snow, so storage for use by the next crop depends on infiltration into frozen soil. Willis et al. (1983) compared eva-

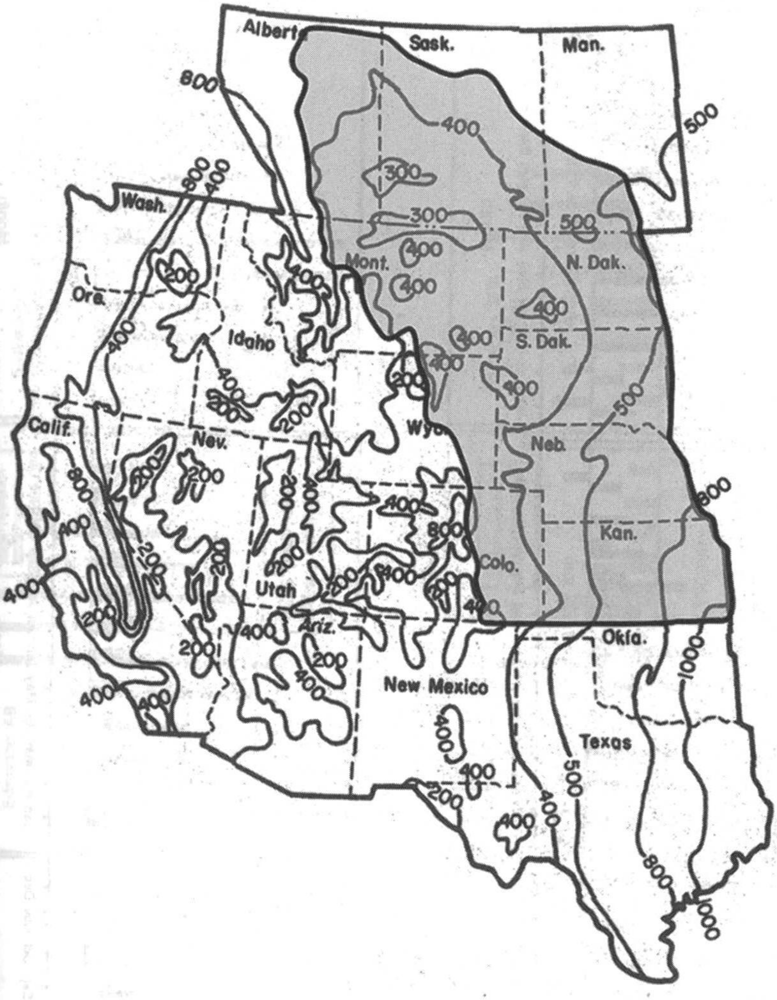

Fig. 9–1. Isohytes for western USA and Canadian Prairies. Precipitation is in millimeters. (From Cannell and Dregne, 1983). Shaded area outlines the main body of dryland agricultural area of the Canadian Prairies and the northern Great Plains.

potranspiration with mean monthly precipitation at Dickinson, ND (Fig. 9–5c). They determined that precipitation matched evapotranspiration through June, but failed to supply adequate water thereafter. July precipitation met about one-half the estimated crop requirement and August supplied only about one-third of crop needs. At Grand Island, NE, July evapotranspiration was three times the amount of precipitation and during August and September precipitation supplied less than one-half of the crop needs (Fig. 9–5d) (Schepers, 1988).

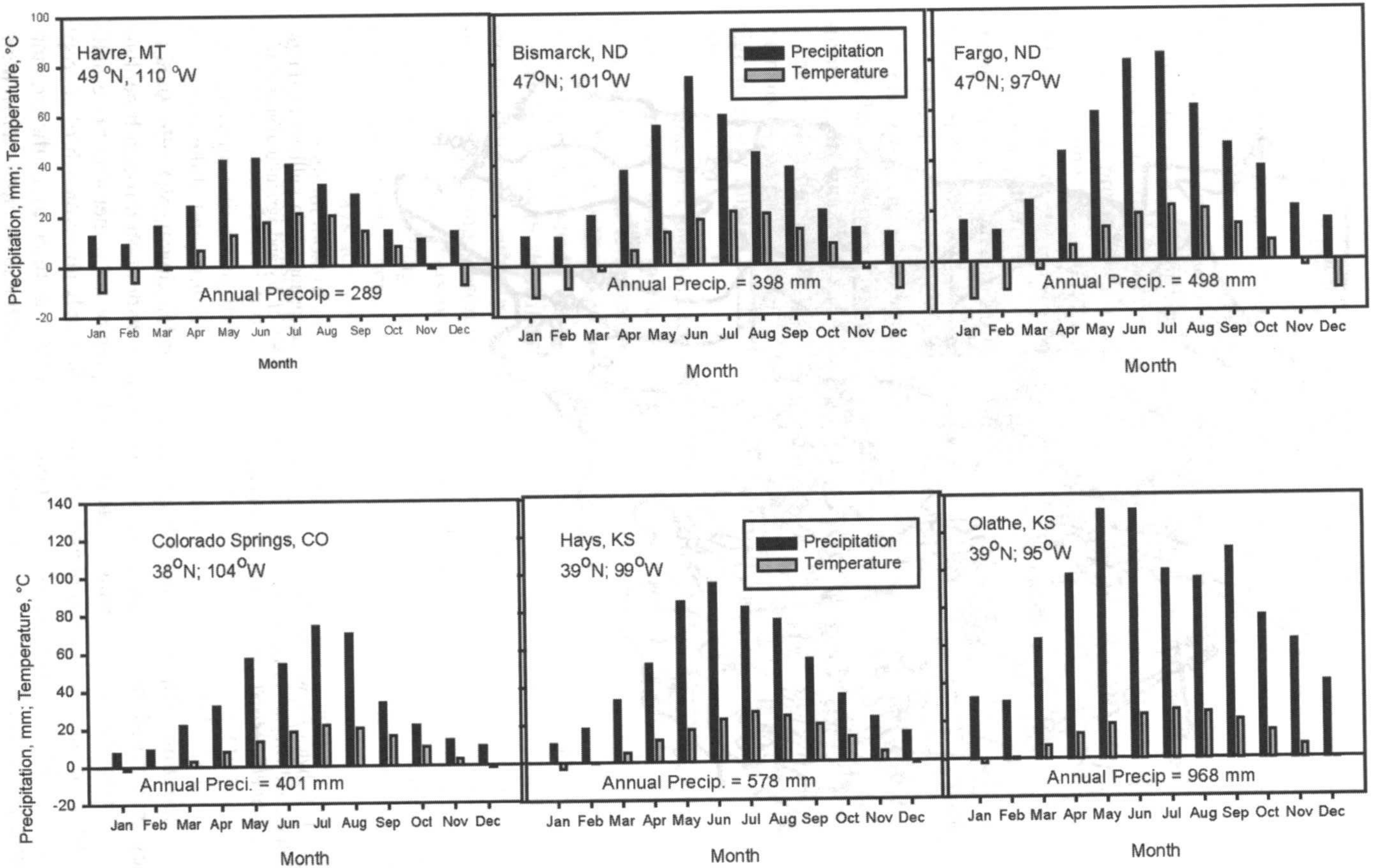

Fig. 9–2. Temperature and precipitation at selected sites in the northern Great Plains. (www.worldclimate.com [verified 22 Nov. 2005]).

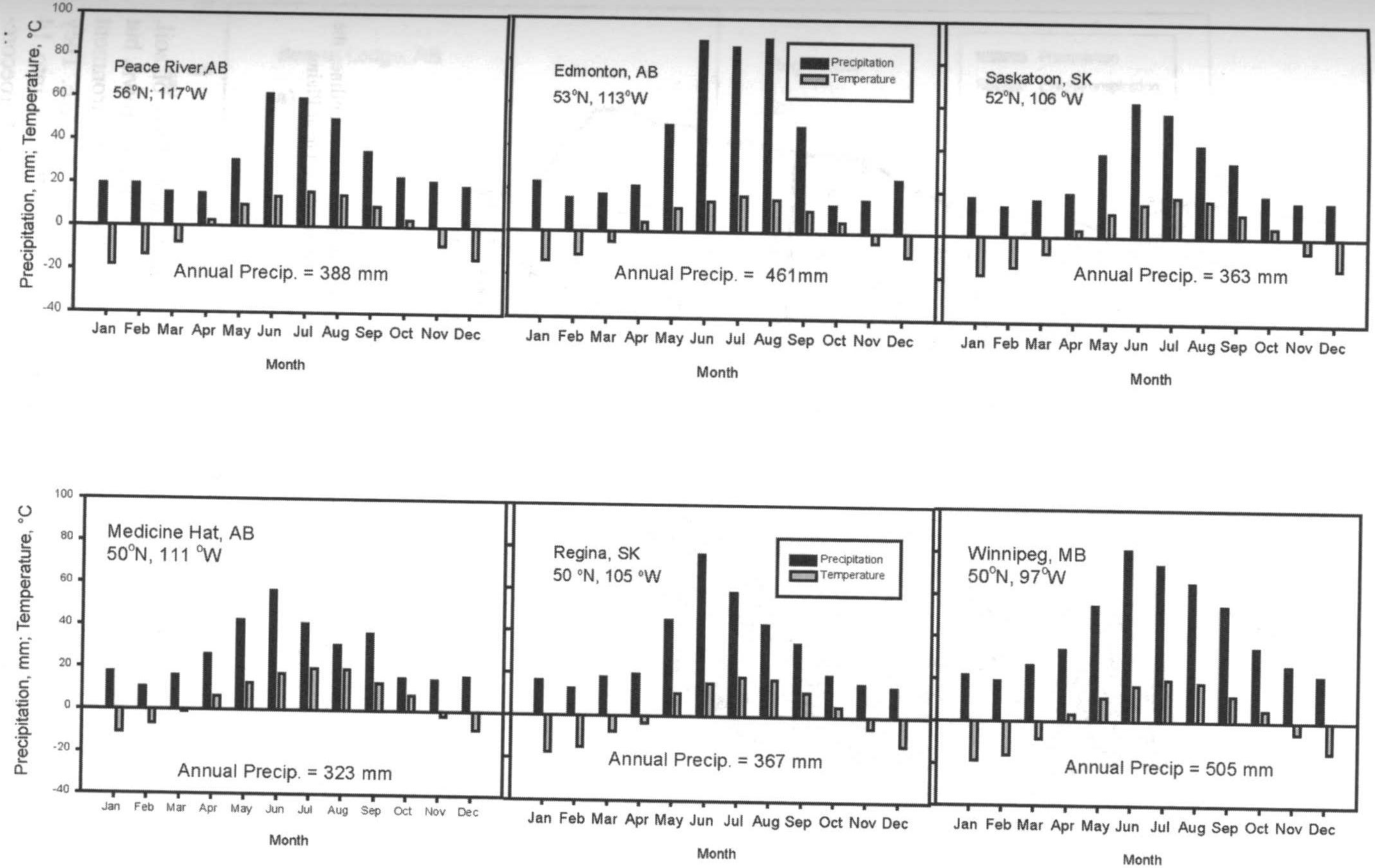

Fig. 9–3. Temperature and precipitation at selected sites in the Canadian Prairies. (Environment Canada).

Fig. 9–4. Mean annual frost-free days (from Cannell and Dregne, 1983). Shaded area outlines the main body of dryland agricultural area of the Canadian Prairies and the northern Great Plains.

AGROECOREGIONS

Padbury et al. (2002) recognized that environmental interactions of soil, climate, and topography dictate not only the type of crops that can be grown, but also the specific management that is likely to be successful. Thus, the environment dictates the long-term success or failure of a particular cropping practice. They proposed delineating the northern Great Plains and Canadian Prairies into 14 agroecoregions, based on soil type, climate, and topography. These Agroecore-

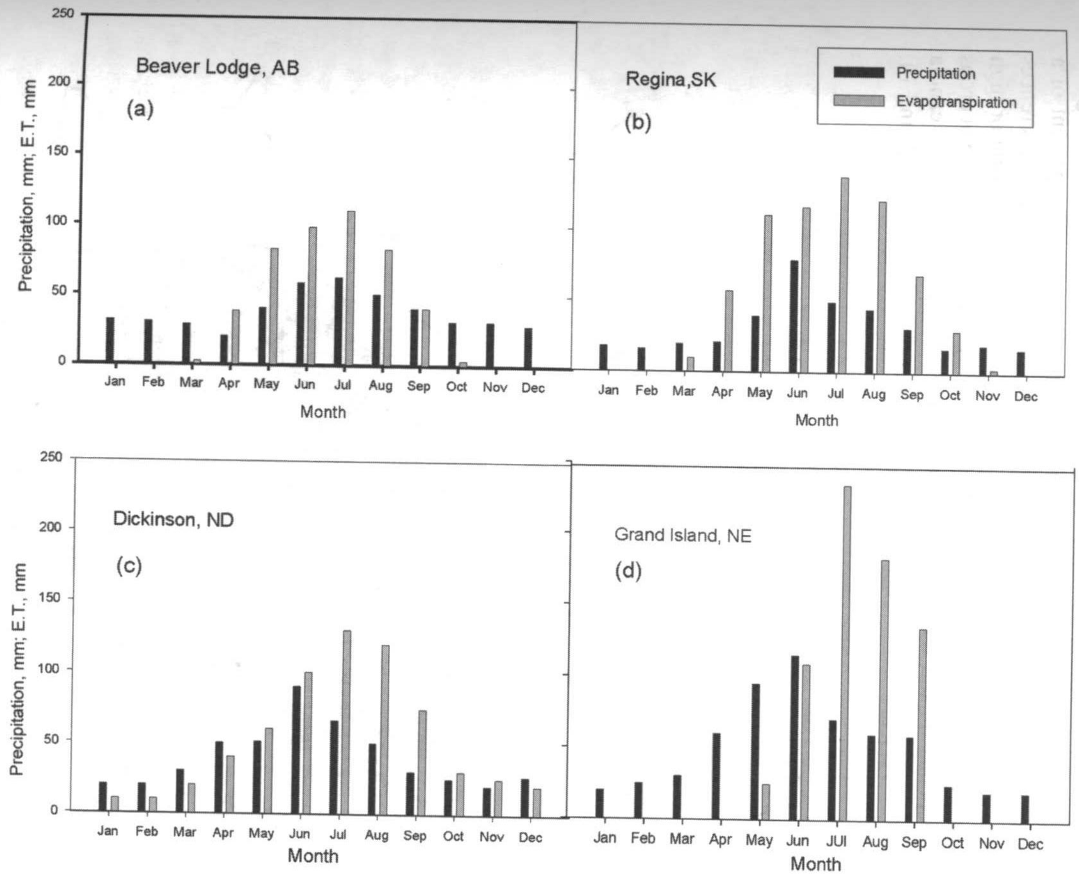

Fig. 9–5. Precipitation and calculated evapotranspiration at two locations in the Canadian Prairies (a and b) (De Jong and Steppuhn, 1983), Dickinson, ND (c) (Willis et al. 1983), and Grand Island, NE (d) (Schepers 1988).

gions cross over state, province, and national borders (Fig. 9–6). However, on the Canadian side, agroecoregions follow those outlined in *A National Ecological Framework for Canada* (Ecological Stratification Working Group, 1995). On the U.S. side, the boundaries result from grouping several Major Land Resources into broader regions (USDA, 1981).

Total landmass, cropland, and a range of climatic variables for each agroecoregion are summarized in Table 9–1 (Padbury et al., 2002). The percent of a particular crop or fallow varies among agroecoregions depending on differences in water stress. Fallow is most prevalent in those with low precipitation or high evapotranspiration (Agroecoregions 1, 4, 6, 8, and 12). Likewise, the type of crops grown depends on the temperature regime. Cool-season crops such as canola (*Brassica napus* L.) are most prevalent in agroecoregions 10, 11, 12, 13, and 14.

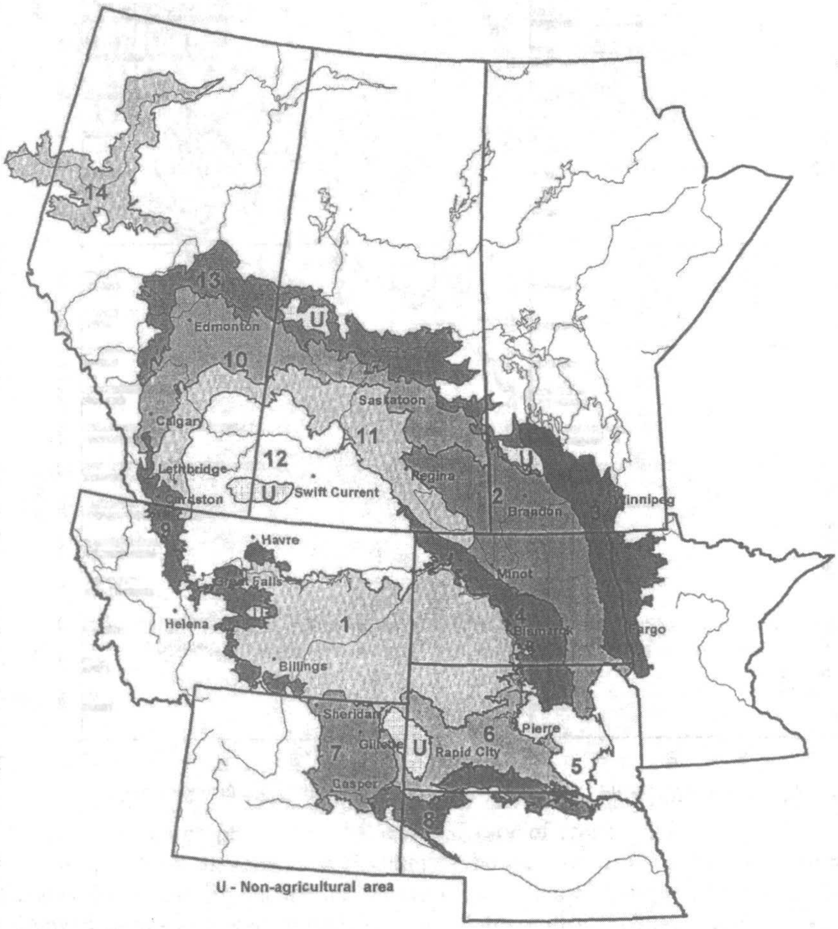

Fig. 9–6. Agroecoregions of the northern Great Plains (from Padbury et al., 2002).

Table 9–1. Total land area, cropland area, and ranges of selected climatic parameters for agroecoregions of the northern Great Plains (adapted form Padbury et al., 2002).

Agroecoregions	Total area	Cropped area	Annual precip.	Evapo-transpiration	Frost-free days	Mean annual temp.
	— million ha —		——— mm ———		d	°C
1	21.4	3.0	300–474	508–660	112–156	5.1–7.3
2	14.3	8.9	375–500	508–635	105–137	1.6–5.2
3	5.7	4.1	483–531	574–635	111–132	1.9–5.0
4	4.2	2.0	350–437	584–610	120–132	4.2–2.0
5	3.2	1.9	375–559	–	149	8.2
6	7.0	0.8	391–465	635–686	130–153	7.2–8.2
7	–	–	300–475	584	121–124	6.8–7.4
8	3.5	0.5	338–627	660	139–147	8.2–10.9
9	4.5	1.0	300–547	–	111	5.3
10	11.0	6.5	400–466	457	95–105	0.5–2.4
11	10.0	6.9	353–414	483–559	03–118	1.1–4.9
12	22.4	10.1	302–356	533–610	113–128	3.6–7.2
13	7.0	1.7	404–493	504	84–120	0.2–3.2
14	11.5	4.5	375–600	178	93–116	−0.0–2.0

Most warm-season crops such as corn (*Zea mays* L.) are grown in agroecoregions 5, 6, 7, and 8. For a complete description of the agroecosystems see Padbury et al. (2002).

Climate Change

It is now generally agreed that the planet has warmed over the last century, although causes remain controversial. However, burning fossil fuels, clearing forests for agricultural and other uses, and past agricultural and industrial practices have all contributed to the increase in atmospheric carbon dioxide (CO_2) that has occurred since pre-industrial times. Many scientists credit increases in atmospheric CO_2 and other radiatively active greenhouse gases for much of the increase in global temperatures. There is considerable controversy over what effects global warming will have on crop production and the ecology in general. It has been well established that some crops will benefit from increased levels of CO_2 through faster growth and more efficient use of water. However general circulation models (GCM) predict that some areas of the planet will have decreased precipitation while other areas will receive more precipitation. The warmer temperatures will also put additional water stress on plants in areas of low precipitation.

Brklacich and Stewart (1995) used the Goddard Institute for Space Studies (GISS) model, the Geophysical Fluid Dynamics Laboratory (GFDL) model, and the United Kingdom Meteorological Office (UKMO) model along with the CERES-wheat (*Triticum aestivum* L.) model to assess the effects of global warming under a 2 X CO_2 scenario for the Canadian Prairies. Results of the three GCM's were mixed with predictions for various locations responding differently with each model. Some locations had predictions of negative impacts, and in other locations the predictions were positive. Temperature increases would lengthen the frost-free growing season and reduce the risk of frost damage, but warmer temperatures would hasten maturation, which would suppress wheat yields. Photosynthesis would be enhanced due to higher levels of CO_2, and water-use efficiency would increase. This would tend to offset potential negative effects of shortened maturation periods. However, all models predicted that the benefits of increased CO_2 on wheat yields would be most pronounced in the drier parts of the prairies. Winter wheat production would likely move north, which could improve water-use efficiency because crop growth occurs in the early spring before periods of peak water stress.

Watson et al. (2001) used more recent versions of the GCMs that predicted less warming than the earlier models. Using these models, along with economic models, they concluded that,

> "Economic welfare may improve for more northerly farm production regions with potential benefits indicated for the lake states, the northern Plains, the mountain region, and the Pacific region."

Although Brklacich and Stewart (1995) discussed the possibility of a warmer climate allowing winter wheat to be grown farther north in Canada, neither of the above studies addressed what effects warming would have on introducing new crops into the region. Milder winters and longer growing seasons could make it feasible for more northerly locations to grow crops now grown exclusively in southern areas, thus increasing the diversity of crops available for inclusion in crop rotations.

Cropping Practices

Traditionally, spring-seeded small grains have been the most common crops grown in the Canadian Prairies, especially hard red spring wheat and durum wheat (*T. durum* Desf.). This practice extends further south into eastern Montana and North Dakota. Fall-seeded hard red winter wheat has been the major crop in central Montana extending south parallel to the Rocky Mountains and including much of South Dakota, Nebraska, Colorado, and Kansas.

Traditional crop management in much of the semiarid northern Great Plains and the Canadian Prairies has rotated small grains, particularly wheat, with summer fallow. Summer fallow is more common in the west due to lower precipitation. The practice of summer fallow became widely adapted after the prevailing drought of the 1930s and principally grew out of the need to manage limited soil water under the erratic rainfall patterns of the region. The extra season of soil water storage afforded by fallowing supplemented precipitation received during the crop year and served to stabilize grain yield and reduce risk of crop failure. Summer fallow also provided an opportunity for methodically controlling weeds, usually with tillage, as they emerged during the fallow season.

Despite the benefit of more consistent yields with summer fallow, research has shown actual amounts of precipitation stored during the fallow season are quite low, especially when using conventional tillage. Typically, only 14 to 25% (Haas et al., 1974; Mathews and Army, 1960) of precipitation received during the fallow season is available for the following year's crop. Low storage efficiencies are due to the high evaporation potential during the hot summer months. The greatest water storage occurs during the fall and early winter months before soils freeze; however, this is not a time of high precipitation. In an attempt to improve precipitation-use efficiency, some researchers have called for increasing the number of crops grown above that of every other year (Peterson et al., 1996; Farahani et al., 1998). In the southern portion of the northern Great Plains, Peterson et al. (1996) have found that warm-season crops such as corn, sorghum [*Sorghum bicolor* (L.) Moench], or sunflower (*Helianthus annuus* L.) can greatly improve water-use efficiency by making use of rainfall when it occurs. In the past, it was thought that the semiarid Great Plains was too dry for corn to be grown without irrigation. However, dryland corn production in western Nebraska, western Kansas, and northeastern Colorado has increased from 5800 ha in 1980 to more than 121 000 hectares by 1997 (Norwood, 2001). Short- season pulse crops that mature early enough for late-season precipitation to partially recharge the soil profile have potential for inclusion in crop rotations with wheat. Furthermore, they do not extract water to the lower limit of extractable water content for wheat, which means that less precipitation is required to fill the profile (Nielson, 2001).

In areas where precipitation is insufficient to fully recharge the soil profile, it is important that methods of increasing winter snow capture and preventing excess soil water evaporation are adopted to facilitate greater cropping intensity. Snow capture in this region, which has prevailing high velocity winter winds, can be accomplished with grass barrier strips (Aase and Siddoway, 1974) and/or by maintaining standing crop stubble over winter. Both of these methods effectively trap blowing snow and hold it on the field (Aase and Siddoway, 1980). The additional water gained from these practices makes it feasible to grow crops annually (Aase and Reitz, 1989). Continuous spring wheat increased total grain production by about 25% over the traditional wheat–fallow rotation in eastern Montana (Fig. 9–7) (Cochran et al., 2000). However, there is an increased risk of crop failure during droughts (Zentner and Campbell, 1988).

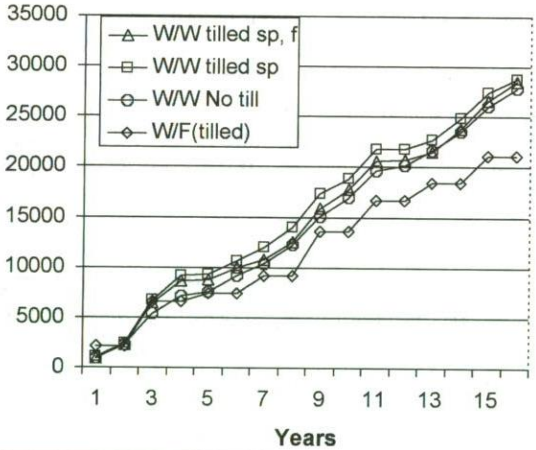

Fig. 9–7. Cumulative grain yield of continuous spring wheat compared with a wheat–fallow rotation. (Cochran et al., 2000).

Fig. 9–8. Direct seeded corn growing in old crop residue.

Further prevention of excess soil water loss is accomplished by maintaining crop residues through the growing season. Development of low disturbance seed drills, conservation tillage techniques, and post-emergent herbicides have contributed to "zero-till," "no-till" or "direct seeding" production systems (Fig. 9–8).

As improved methods of soil water conservation were developed and adopted, crop diversification increased throughout the semiarid northern Great Plains. Much of this trend has been encouraged by perennially dim market prospects for cereal grains. In the semiarid region of Saskatchewan (Brown and Dark Brown soil zones), oilseed and pulse crops have increased from <8% of the seeded area in 1991 to 32% of the seeded area in 2000 (Fig. 9–9). Accompanying this increase in diversity has been a dramatic reduction in the practice of summer fallow, falling from 38% of cropland in 1991 to only 24% in 2000.

Tillage

Agricultural expansion in the Canadian Prairies and northern Great Plains was initiated and has developed through most of the past century with the use of some form of tillage. Use of the moldboard plow allowed thousands of acres of prairie sod to be overturned as well as subsequent crop residues in an effort to prepare an acceptable crop seedbed. Other aggressive methods of tillage have used the tandem disk for seedbed preparation as well as for weed control. The general trend from these initial years through the present has been to reduce the intensity and frequency of soil disturbance with the advent of "minimum-" or

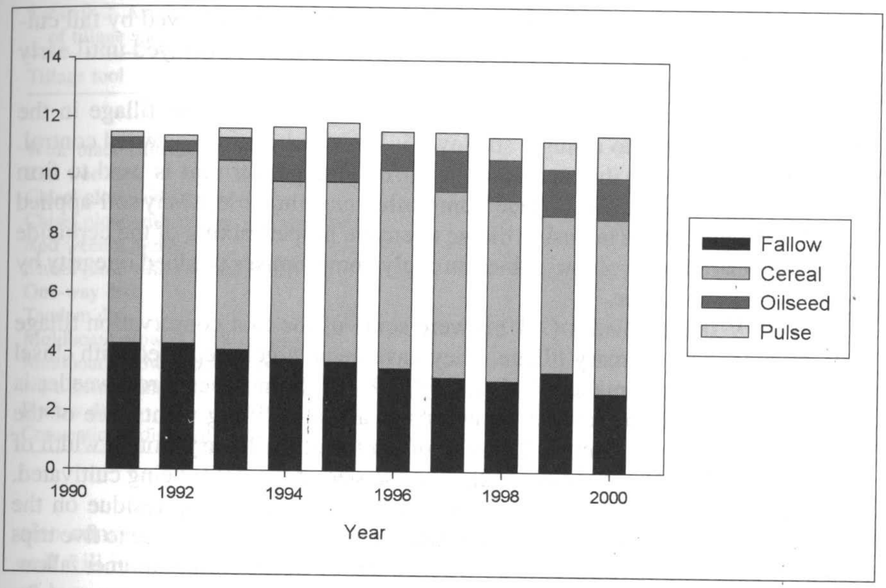

Fig. 9–9. Change in cropland distribution in the Saskatchewan semiarid region.

"no-till" soil conservation techniques. Because of the large-scale erosion that occurred during the drought of the 1930s when clean tillage was a common practice, the need to maintain crop residues on the soil surface has been recognized for several decades.

Common tillage practices can vary among subregions of the Great Plains and Canadian Prairies in relation to precipitation received since rainfall influences production and thus the subsequent amount of crop residue that must be managed. In subhumid areas, tillage might begin after harvest, once soils have been sufficiently moistened by fall rains, to initiate decomposition of crop residues.

The first fall tillage operation might be a high-speed (13–16 km h^{-1}) pass of spring-tined harrows conducted during hot dry conditions to break crop residues into smaller pieces and to spread chaff evenly. Subsequent to harrowing, further fall tillage might involve a cultivator with wide sweeps or a tandem disc. In cereal crops where residue amounts are high, tandem discs are typically operated at depths of 10 to 15 cm to chop residues into smaller pieces and bury up to 50% of the residue within the soil to begin decomposition. Subsequent tillage later in the fall or spring typically includes a field cultivator operated at a 7- to 10-cm depth to smooth the soil surface and prevent further loss of protective crop residues. With low residue crops such as lentil (*Lens culinaris* Medik.), flax (*Linum usitatissimum* L.) or field pea (*Pisum sativum* L.), the first tillage operation is often a cultivator equipped with sweeps, and might be delayed until spring to provide some soil protection from wind and water erosion.

In the northern and eastern fringes of the Canadian Prairies stubble burning in cereal and flax crops remains a common practice, usually designed to eliminate the mass of residue deposited in the windrow immediately behind the harvester, but occasionally including the entire field. Burning may be followed by fall cultivation with wide (25–40 cm) sweeps or cultivation may be delayed until early spring.

To prevent loss of valuable seedbed moisture, pre-seeding tillage in the spring is often limited to a single shallow (5–7 cm) cultivation for weed control. Immediately following this operation, a harrow and packer unit is used to firm the seedbed and seal the soil surface from further moisture loss. Many soil-applied herbicides require more intensive tillage to ensure proper mixing of the herbicide within the desired soil volume, which strongly compromises seedbed integrity by drying out this soil zone.

Wide V-shaped blades (>1 m) were some of the first conservation tillage tools developed for primary tillage. They have been largely replaced with chisel plows equipped with smaller V blades (Fig. 9–10). Sometimes a rod weeder is attached just behind the last set of sweeps to assist in lifting plants free of the soil and improve weed control. The size of equipment will vary from a width of about 6 m to more than 20 m depending on the size of the fields being cultivated. The objective is to kill live vegetation and leave adequate crop residue on the surface to stabilize the soil from wind or water erosion. Typically, three to five trips across the field may be required to keep a field free of weeds during summer fallow. Each trip incorporates crop residue, reducing the amount available to protect the soil. Table 9–2 shows the amount of crop residue incorporated with each trip of some commonly used tillage equipment (Johnson, 1983; Troeh et al., 1999).

The use of herbicides to control vegetation reduces the number of tillage trips required, thus maintaining more crop residue on the soil surface. This may

Fig. 9–10. Chisel plow with rod weeder attached behind rear V blades.

Table 9–2. Average reductions of surface wheat crop residues for each operation with various types of tillage and planting equipment (adapted from Johnson, 1983; Troeh et al., 1999).

Tillage tool	Residue reduction per operation
	%
Wide blade cultivator	10
Rod weeder	10
Chisel plow with sweeps	20
Chisel plow with sweeps and rod weeder	10
Rod weeder alone	10
Chisel plow with twested points	50
One-way disk	50
Tandem disk	50
Moldboard plow (13–18-cm deep)	90
Moldboard plow (>20-cm deep)	100
No-till slot planter	10
Furrow drill	20
Conventional disk drill	10

also conserve water in areas of moderate summer rainfall because tilling moist soil will increase evaporative water loss by 5 to 8 mm (Greb et al., 1979). In areas of low summer rainfall or during times of low rainfall, tillage is used to establish a dust mulch, which reduces evaporation by increasing the resistance to vapor flow (Papendick et al., 1973). In Montana, it is common practice to begin the summer fallow period with one or two applications of a burn down herbicide followed by shallow tillage with a chisel plow in July or August to provide a dust mulch to seal off evaporation from below the tillage layer. Chemical fallow, another common practice, reduces the amount of water lost to evaporation by not performing tillage. Thus, wheat stubble is left standing in place to trap snow and results in a more uniform distribution of water across the field the following spring (Aase and Siddoway, 1980; Peterson et al., 1996). Smika (1990) reported a 9% increase in available water and a 10% increase in wheat yield with chemical fallow compared with tilled fallow in central Colorado.

With the shift to less tillage and maintaining crop residues on the soil surface, it has become increasingly evident to farmers that their tillage system begins with the harvesting operation. Uniformly spreading straw and chaff promotes better weed control with herbicides, better performance of tillage and planting equipment, and more uniform emergence of crops.

Gravity-flow, double-disc, or hoe type seeders have steadily given way to various air delivery units that have the capacity to plant large areas in a relatively short time. Early models consisted of a heavy-duty cultivator with narrow sweeps equipped with an air delivery system to transport seed from a large bin to the rear of the sweeps. In recent years many types of openers have been developed to improve seed placement and stand establishment. Air 'seeders' are differentiated from air 'drills' based on the principle of tillage. Air seeders are designed to combine a final cross-field tillage operation using narrow sweeps (10–15 cm) with seeding, followed immediately by coil packers or wide tires to improve seed-to-soil contact. Conversely, air drills are designed to focus on seed and fertilizer placement, with varying levels of soil disturbance occurring during the actual

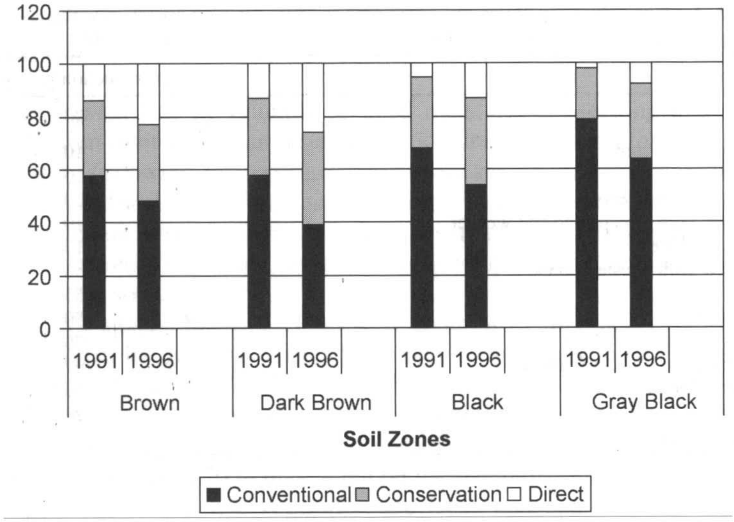

Fig. 9–11. Change in tillage practices in the Canadian Prairies from 1991 to 1996.

seeding operation. Although either general type of air delivery unit can be used in tillage-based or direct-seeding systems, air seeders are typically used in tillage-based systems while air drills are the tools of choice for direct-seeding systems. Commercial seeding openers are now available with the capacity to apply fertilizer with the seed as a pop-up fertilizer and in a band adjacent to the seed but at adequate distance to avoid seedling injury in all kinds of soil conditions, and are simply too numerous to provide a complete list in this chapter.

Direct seeding has revolutionized northern Great Plains agricultural systems with rapid farmer adoption of these systems occurring in the 1990s. In many districts of the Canadian Prairies, direct-seeding systems have become the new 'conventional' tillage system. The latest statistical data available for the Canadian Prairies is from 1996, which greatly underestimates current farm adoption of this technology (Fig. 9–11). In the USA, northern Great Plains adoption rates have been slower (Fig. 9–12). Adoption of direct-seeding systems is due to several factors, chief of which are increased time, labor, and capital-use efficiencies, improvements in seeder and opener design, inexpensive herbicides and applied education by well-organized farm associations such as the Manitoba-North Dakota Zero Till Association.

Emerging factors that will continue to spur the adoption of direct-seeding systems include increases in fuel prices, and the growing concern about the role of agriculture in greenhouse gas emissions and reductions. Leasing of offset carbon (C) credits to energy companies has already begun (Aeschliman and Ross, 2002). Direct-seeding systems, also offer farmers the potential to greatly enlarge farm size without increasing the labor requirements (Aeschliman and Ross 2002), which will likely have profound implications for rural communities.

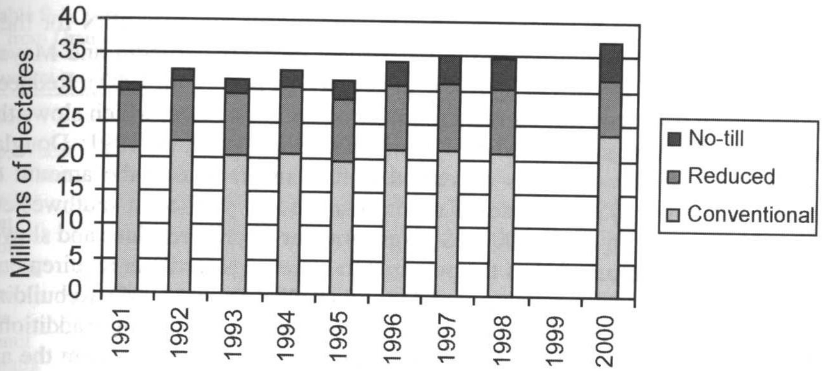

Fig. 9–12. Total seeded area managed in no-till, reduced tillage (including ridge tillage) and conventional tillage (<30% crop residues on surface) in Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming 1991–2000. Data not available for 1999 (Source: Conservation Tillage Information Center, Purdue Univ., West Lafayette, IN).

Fertility

When agriculture began in the region, native prairie soils were generally fertile. Relatively high levels of organic matter supplied crops during the initial years with adequate mineral nutrition. Summer fallow increased mineralization of nitrogen (N) from soil organic matter (SOM) through increased soil aeration and higher soil water content during the warm months. Thus, an adequate supply of mineral N was available in the northern Great Plains and Canadian Prairies to supply the needs of the crops grown. However, prolonged cropping of these prairie soils has slowly depleted soil N such that fertilizer N is now required for optimum yields and good crop quality in most areas.

Nitrogen is closely associated with soil C, or more generally, with SOM. The C/N ratio of SOM is generally assumed to average 10:1, but can range as narrow as 8:1 for well-developed soils (El-Harris et al., 1983) and has been reported to be as wide as 18:1 in newly cleared forest soils (Cochran et al., 1989). Quality hard red spring and winter wheat grown in the northern Great Plains with a protein content of 14% or higher often receives a premium price. Assuming a grain yield of 2000 kg ha^{-1}, about 50 kg N ha^{-1} is removed by the crop. If this N comes entirely from mineralization of SOM, about 500 kg C ha^{-1} is released as CO_2. Therefore, decreases of valuable soil organic matter has been accompanied by significant increases in atmospheric CO_2, which as previously discussed, are predicted to increase global temperatures. Recent research has shown that by increasing SOM, principally through the cessation of tillage, production agriculture can be enlisted to reduce greenhouse gas emissions (Lal et al., 1998).

Reduced and no-till management practices have led to improved precipitation-use efficiencies and increased cropping intensity, which in turn has fostered a greater dependence on mineral fertilizers because more nutrients are removed with additional cropping intensity (Aase and Pikul, 1995; Peterson et al., 1996; Farahani et al., 1998). An exception to this scenario occurs when legumes replace fallow in the rotation because the legume crops fix the majority of N for their nutritional needs and cycle N to the subsequent crop (Badaruddin and Meyer, 1994; Beckie and Brandt, 1997; Beckie et al., 1997; Pikul et al., 1997). Reduced and no-tillage practices leave more crop residue on the surface, which slows the decomposition processes including N mineralization (Cochran, 1991; Douglas and Rickman, 1992). This has decreased C flux and increased the amount of partially decomposed plant material on or near the soil surface in southwestern Saskatchewan (Curtin et al., 2000). Slower turnover of crop residues and slower mineralization of organic N has the potential to increase N fertilizer requirements during the first few years in reduced and no-till (Kolberg et al., 1996). Rebuilding the SOM lost to mineralization over the last several decades will require additional N inputs either from legumes, free living dinitrogen (N_2) fixers or from the application of fertilizer N. Calculations indicate that a decrease in SOM of 1% in a ha-slice 15-cm thick leads to a loss of 2 Mg of N ha^{-1}. The SOM in many cultivated soils in the northern Great Plains has declined by 1 percentage point or more since cultivation began (Janzen et al., 1998).

Phosphorus (P) is only loosely tied to crop residues and SOM (McGill and Cole, 1981). Sparrow et al. (1990) found that 90% of total soil P was in the organic form in a boreal forest and was found primarily in SOM and semi-decomposed organic material on the forest floor. In comparison, about 70% was in the mineral form on land that had been cleared and cropped for 5 or more years. Laboratory incubation studies indicated P was mineralized primarily during the respiration of easily decomposable organic matter. This has important implications for P cycling when changing from intensive tillage to no-tillage practices. Phosphorus is released early in the decomposition of crop residues, but release may be slightly delayed in surface residues because decomposition of crop residues is delayed when left on the soil surface (Cochran, 1991). This would put more reliance on fertilizer P during crop emergence.

Preceding crops or fallow can influence P nutrition due to their effect on vesicular–arbuscular mycorrhizae (VAM). These fungi infect the roots and form a symbiotic relationship with many plant species and penetrate areas of the soil that the roots cannot, effectively increasing the zone of exploration and uptake of immobile nutrients such as P and zinc (Zn) (Grant et al., 2002). Vesicular-arbuscular mycorrhizae depend on a living host plant; therefore, fallowing or planting crops that do not serve as hosts can reduce P uptake by the subsequent crop.

Maintaining crop yield and quality over time requires the replacement of nutrients removed by previous crops. The amounts of major nutrients removed by common crops grown in the northern Great Plains are shown in Table 9–3 (Grant et al., 2002). Yields will vary greatly between crops harvested: thus, the amount of nutrient removed is yield dependent. Soil testing before planting can ascertain whether some or all of the mineral nutrients are present in soil reserves at levels adequate to supply the crop. For instance, an estimation of applied N requirements can be calculated using soil test data and previous yield history. However, there is considerable variation in the distribution and amount of precipitation from year to year, which makes estimating fertilizer rates unreliable. Goos et al. (1982) determined that N sufficiency for the past season could be determined by the

Table 9–3. Amounts of plant nutrients removed by harvested portion of some major crops (adapted from Grant et al. 2002).

Nutrient	N	P	K	S
Crop		g kg^{-1} of harvested yield		
Sp, Wheat	23–27	3.7–4.8	5.6–6.7	1.5–2.2
W. Wheat	16–19	3.2–4.2	4.2–5.4.2	2.0–2.6
Barley	19–22	3.2–4.2	4.9–6.0	1.6–2.1
Oat	17–21	3.1–3.9	4.5–5.3	1.1–1.7
Corn	16–19	3.0–3.7	3.7–4.1	1.1–1.3
Canola	35–42	8.2–9.7	7.6–9.7	5.6–6.6
Flax	39–42	4.7–5.4	8.0–10.1	2.7–4.0
Pea	35–43	4.5–5.3	8.9–10.7	1.7–2.8
Lentil	30–37	3.9–4.9	13.4–16.3	1.9–2.9
Alfalfa	26–32	2.6–3.2	22.4–27	2.7–3.3

protein content of the harvested wheat. They determined that the critical protein level for hard red winter wheat was 11.5%. Fertilizing below this level reduced yield, while fertilizing above the critical level increased protein content but not yield. Engel et al. (1999) used a similar approach in hard red spring wheat where the critical yield-protein breakpoint occurred at 13.2% protein (10% grain moisture).There has been success in using this information to optimize rates of N fertilizer across the field landscape, gaining more uniform quality and increased yield compared to uniform single rate N applications (Long et al., 1999). Thus, protein content of wheat can be used with weather data to evaluate the N fertilizer program and make modifications if needed.

Grain yield and protein can be increased by management practices that maintain available soil N during head fill (Smika and Grabouski, 1976; Cochran et al., 1978). Foliar application of low rates of N have also successfully increased grain yields and protein content of wheat in dryland areas (Selles et al., 2000), but requires an extra trip across the field. Campbell et al. (1983) found that planting wheat after flax increased grain yield and protein; presumably, the wheat was able to obtain N during head fill that was at a depth below that removed by the flax. Although pulse crops remove about as much N as they fix, N uptake and protein content have been found to increase after pulse crops (Grant et al., 2002). There is substantial evidence that increasing crop intensity (with a well-balanced fertility program) increases mineralizable N over the long term by building up the soil N reserves (Wood et al., 1990; Campbell et al., 1993; Wienhold and Halvorson, 1999).

Placing the fertilizer close to the seed has been shown to enhance crop uptake and reduce the competition from weeds (Cochran et al., 1993). Many drills and air seeders are now equipped to apply some of the fertilizer in the seed row to give the crop a boost during germination and early growth, and many of them can also apply the bulk of the fertilizer to the side and below the seed to avoid injury to the seedling plant. Furthermore, the application of N and P with the seed has reduced the severity of some root diseases of winter wheat in the Pacific Northwest (R.J. Cook, WSU, Pullman, WA, personal communication, 2002). Presumably, the plant has more seedling vigor due to ready access to the fertilizer and can overcome some of the deleterious effects of the disease. Although placing fertilizer with the seed has benefited some crops, small-seeded crops such as flax and canola are sensitive to fertilizer in the seed zone (Grant et al., 2002). Applying both N and P fertilizer together in a band has been shown to increase P uptake in soils with pH >7.0 (Halvorson, 1994).

Sulfur (S) response in the northern Great Plains is rare for most major crops (Halvorson, 1994), but canola has substantially higher S requirements than most crops (Grant et al., 2002) and care should be taken to ensure soil S levels are adequate. Growers should also be aware that the high S requirement of canola could remove substantial amounts of S from the soil and leave the soil deficient in S for succeeding crops.

There is evidence that chloride (Cl) may be deficient for some crops and in some locations in the Great Plains. For instance, spring and winter wheat have responded to additions of Cl at several locations in the northern Great Plains (Engle et al., 1994; Grant et al., 2002). Some of the response was attributed to suppression of powdery mildew (*Erysiphe graminis f.* sp. *tritici)*, leaf rust (*Puccinia recondita* f. sp. *tritici*), and physiological leaf spot. However, not all responses to Cl have been attributed to disease suppression. (Engle et al., 1994)

WEEDS, DISEASE, AND INSECT PESTS

Changes in agricultural pest control have come at an increasingly rapid rate over the past 150 yr. The newly available expanse of land in the Great Plains opened the door for tremendous agricultural expansion starting in the mid-1800s. With the development of this new land came the pressures of feeding an ever-increasing population. However, limits of the land were quickly reached, and the need to intensify agricultural production became the new challenge. The ability to produce more from the same land grew with the availability of more advanced technologies, such as increased mechanization, improved crop genetics, and, in particular, the development of pesticides. Greater intensification has inevitably led to more specialization and the utilization of monoculture production systems. As a consequence, allowing well-adapted pests to proliferate has altered the composition of "the pest complex," reinforcing the need for newer and better pesticides (Matson et al., 1997). Nowhere has this been more evident than in the northern Great Plains and Canadian Prairies, where the concentration of wheat production has seen the influx of specialized pests such as the wheat stem sawfly (*Cephus cinctus*), the orange wheat blossom midge (*Sitodiplosis malellana*), and the Russian wheat aphid [*Diuraphis noxia* (Mordw.)]. Herbicide-resistant weeds and fungal wheat diseases have also increased substantially in some areas.

Continuing efforts to further intensify agricultural production through dependence on new technologies began to raise questions of whether such a production system could be maintained (Matson et al., 1997). These questions first began to arise in the 1960s along with the development of alternative production strategies, which were often borrowed from the "organic farming" philosophy. These strategies have also included principles used by practitioners of "integrated pest management" or IPM, which was initially developed in the late 1950s and early 1960s. Often labeled as "sustainable agriculture" this philosophy has steadily gained wider acceptance since the 1980s.

One of the primary tenets of sustainable agriculture is the importance of maintaining biological diversity in the system. Outside of its most obvious function of producing food or fiber, the agroecosystem must also recycle nutrients, regulate microclimate and local hydrological processes, suppress undesirable organisms, and detoxify noxious chemicals. Since most of these processes are biologically mediated, it is important to maintain the biological integrity and diversity within the system (Altieri, 1999), which can also ensure against declines in production over the long term (Yachi and Loreau, 1999). Diversifying crop rotations to include broad leaf and narrow leaf plants as well as warm- and cool-season plants offers a variety of food substrates and growth habits to maintain soil biological diversity and break disease cycles. Diversification also allows the use of alternate herbicides to avoid the build up of chemical-resistant weeds and reduces insect damage by growing nonhost crops.

The severe winters with relatively short growing seasons limit some pests while promoting others. For instance, many aphid species do not survive the cold winters of the northern Great Plains and Canadian Prairies (Philip and Mengersen, 1989). However, soil-borne root diseases may be enhanced in winter wheat due to prolonged dormancy of the crop (Cook and Veseth, 1991).

Weeds

Research in cropland weed management over the past 20 yr has increasingly expanded its focus to include factors beyond those related to application of herbicides. Factors such as crop rotation, and fertility and tillage management have been included to examine how specific cropping practices can promote crop establishment and growth relative to weeds. Thus a more ecologically based approach is being emphasized. Developed under the larger concept of integrated pest management (IPM), research efforts in integrated weed management (IWM), were in part initiated because of the development of weed resistance to herbicides, increasingly narrow farm profit margins, and environmental issues related to the widespread increase in use of agricultural chemicals.

Weed species tend to proliferate where agronomic practices favor their life cycle and growth habits. In the northern parts of the region where spring wheat is the dominant crop, common broadleaf summer annual weeds have been wild mustard [*Brassica kaber* (DC.) L.C. Wheeler], kochia [*Kochia scoparia* (L.) Schrad.], wild buckwheat (*Polygonum convolvulus* L.), sunflowers (*Helianthus* spp.), Russian thistle (*Salsola iberica* Sennen & Pau), lambsquarters (*Chenopodium* spp.), and pigweeds (*Amaranthus* spp.). Problem grassy weeds have been wild oat (*Avena fatua* L.) and green foxtail (*Setaris viridis* (L.) Beauv.) while dominant perennial species include Canada thistle (*Cirsium arvensis* (L.) Scop.), quackgrass [*Elytrigia repens* (L.) Nevski], and foxtail barley (*Hordeum jubatum* L.). Further south in the region where fall-seeded winter wheat is the most common crop, winter annual weeds adapt well to its cultivation. These especially include downy brome (*Bromus tectorum* L.), jointed goatgrass (*Aegilops cylindrica* Host), and Italian ryegrass (*Lolium multiforum* Lam.). Other winter annual species, depending on location and management practices, can include pennycress (*Thlapsi arvense* L.), turnip weed (*Rapistrum rugosum* (L.) All.), wild radish (*Lactuca serriola* L.), henbit (*Lamium amplexicaule* L.), and gromwells (*Lithospermum* spp.) (Derksen et al., 2002).

As discussed earlier, the trend in tillage management has been to decrease tillage intensity. As a consequence of changing from conventional to reduced and no-till management, weed species shifts have also occurred across the region. Often it is difficult to predict which changes in weed species composition will occur or how extensive the shift will be since management, weed biology and environmental conditions all influence crop–weed competition. In general, weed species common before adoption of conservation tillage have not disappeared and many are still present (Thomas et al., 1997). For example, the perennial species, field bindweed (*Convolvulus arvensis* L.) and Canada thistle, have remained problem weeds in all tillage systems with control only accomplished by persistent methods (Cook and Veseth, 1991). Some species common in conventional tillage have shown a preference for conservation tillage (Moyer et al., 1994; Derksen et al., 1993) and often exhibit a winter annual growth habit within the protective layer of residue common to no-till management. New problem winter annuals include: narrowleaf hawksbeard (*Crepis tectorum* L.), nightflowering catchfly (*Silene noctiflora* L.), redstem filaree [*Erodium cicutarium* (L.) L'Her. ex Ait.], salsify species (*Tragopogon dubius* Scop. and *Tragopogon pratensis* L.), catchweed bedstraw (*Galium aparine* L.), greenflower pepperweed (*Lepidium densiflorum* Schrad.), horseweed [*Conyza canadensis* (L.) Cronq.], wood whitlowgrass (*Draba nemorosa* L.), American dragonhead (*Dracocephalum parviflorum* Nutt.), and pygmyflower/northern rockjasmine (*Androsaece septentrionalis* L.) (Derksen et al., 1996; Moyer et al., 1994).

Many producers of the region, particularly in Canada have found that diversifying crops grown in rotation can substantially facilitate effective weed control (Moyer et al., 1994; Blackshaw et al., 1994). Including crops with both spring and winter growth habits provides more opportunities to vary control measures, for example, in the time and type of herbicide applied. In places further north where winter annual crops are seldom grown or do not survive, adding a hardy perennial crop can also disrupt weed life cycles and reduce weed seed production (Kegode et al., 1999). A further level of diversification can be accomplished by also including crops of differing growth habits within the broader designations of spring or winter crops and grass or broadleaf crops. For example, this has served to intensify cropping over a 4- to 5-yr term in South Dakota (Beck, 2005), where distinctions are also made between warm- and cool-season crops within each crop type. The goal is to provide a variety of planting dates and herbicide options to keep weed populations off-balance. Crop diversity also serves to spread the farm workload and price risk.

When comparing the relative influence of the types of crops grown and tillage management on weeds, Canadian researchers have found crop choice and crop sequence to impact weed populations more than tillage (Thomas et al., 1996). Recommendations concerning changes in tillage practice from conventional to reduced or no-till within the Great Plains have usually been coupled with the promotion of crop diversification for economic reasons (Peterson et al., 1993a, 1993b), as well as for weed management. Growers' experiences in attempting such management changes across the region have borne this out. Often more innovative producers will experiment with new management techniques concurrently, or even ahead of research efforts. To minimize possible failures among producers, more recent research efforts are trying to expand the utility of integrated weed management techniques from smaller-scale plot and field studies that describe current seasonal effects to a more predictive role at the larger scale of the farm or agroecosystem (Swanton and Murphy, 1996).

Diseases

Plant disease control is an important management consideration even in dryland agroecosystems. The presence and severity of a plant disease is determined by the interaction of susceptible crops, the presence of a pathogen, and favorable environmental conditions. All three factors are required for disease development (Krupinsky et al., 2002). Management practices that alter any of these factors will influence the incidence and severity of diseases. Generally, pathogens attack a specific plant species or a family of plants. Diseases of cereals generally do not affect broadleaf plants and vice versa. Rotations that contain a diversity of cereal and broad leaf plants (cool and warm season) reduce the risk of soil and residue borne diseases provided weed species that are host to the pathogen are controlled (Cook and Veseth, 1991). Including pulse crops in diverse rotations has been attributed to enhancing the population and activity of beneficial soil organisms and reducing the impact of cereal root rot (Cook and Veseth, 1991).

Tillage can have a major impact on the severity of some diseases. Many pathogens continue to sporulate longer on surface residues than if they are incorporated. For example, *Mycosphaerlla pinodes* (Berk & Bloxom) Vegestergen, which causes mycosphaerella blight of pea, survives much longer on pea residue on the surface than on buried residue. However, survival of *Col. truncatum*, which causes anthracnose of lentil, is greater on buried residue than on surface residue (Krupinsky et al., 2002). Surface residues modify the soil moisture and temperature, which can have a positive or negative affect on disease severity. For example, *Coc. sativus* on cereal roots declined under reduced tillage, but *Fusarium* spp. increased. Furthermore, it has been speculated that reduced tillage systems may increase the sustainability of agriculture systems by taking advantage of natural biological processes for pest management (Krupinsky et al., 2002).

Krupinsky et al. (2002) site studies showing that fields with low levels of N have higher levels of tan spot than those adequately fertilized. Engle et al. (1994) found that Cl deficiency increased the incidence of leaf spot in some cultivars of winter wheat. Both of these papers support the concept that balanced plant nutrition reduces plant stress, improves physiological resistance, and decreases the risk of disease.

CEREAL CROPS

Common bunt (stinking smut) has been recognized since the 18th century and infects wheat worldwide. It is caused by two fungi: *Tilletia tritici* (Syn. *T.*

caries) and *T. laevis* (*T. foetida*). Infection of the emerging seedling occurs from spores in the soil or from spores on contaminated seed. Mycelia grow in the intercellular space and spreads throughout the plant reaching the head where it forms teliospores resulting in bunt ball instead of seed. Not only is seed yield reduced, but also the teliospores give the contaminated seed a pungent, fishy odor, and a darkened appearance, which reduces the value of the grain (Wiese, 1991). Control can be achieved by resistant varieties, but resistance is usually short lived. The best control is achieved with fungicidal seed treatment.

Fusarium head blight (FHB), also called scab, occurs on all of the small grain cereal crops and is most prevalent in humid regions of the northern Great Plains. In severe cases significant yield losses may result from floret sterility and poor seed filling. Several *Fusarium* species cause scab, but *F. gremineatum* is the main species affecting crops in the northern Great Plains. It overwinters on host residues such as cornstalks, wheat residue, and some grasses. Conida or ascopores from these residues are carried to the wheat heads by air currents. During warm, moist weather, the spores germinate and invade the flower parts, glumes, or other portions of the spike. Infections are most serious at anthesis (Wiese, 1991). Control of scab has been difficult. Chemical seed treatment has reduced infections to some degree, but many are ineffective against internal inoculums. Some degree of control has also been accomplished by application of fungicides at the flowering stage. Deep incorporation of crop residues is also desirable, but may result in increased soil erosion. Crop rotations with at least a 1-yr break from cereal and grass cultivation is recommended. Although there are some differences in the incidence of head blight among cultivars, plant resistance has not been effective in the past. However, there are new cultivars coming that offer increased resistance (Stack, 1999).

Stem rusts (*Puccina graminis* f. sp. *tritici*) and leaf rusts (*P. recondite* f. sp. *tritici*) occur in winter and spring wheat in the Great Plains. Average daily temperatures of 20°C or above during heading encourage stem rusts, while temperatures ranging between 15 and 20°C promote leaf rusts (Cook and Veseth, 1991). Rust epidemics occur when compatible wheat plants are grown over a large area and rust fungi are present. With ideal temperature and humidity, infection is completed in 6 to 8 h and urediospores are produced in 10 d. Urediospores are readily dispersed over long distances by wind, thus an infrequent race can become dominant in a few weeks. Alternate host plants support the sexual stages of the rust fungi and can be sources of new virulent forms (Wiese, 1991).

Control of stem rust is best achieved by use of resistant crop varieties. However, destroying alternate hosts interrupts the life cycle of rusts, limits their diversity, and indirectly increases stability of resistant cultivars. Growing different cultivars within a production area restricts rust damage because the genetic diversity in the crop requires corresponding diversity in the rust population for epidemics to occur.

Soil-borne diseases of wheat occur in areas of low to high precipitation. In dry soils, *Fusarium* species and *Cochliobolus sative* cause common root rot. Infection is from spores in the soil and occurs on the subcrown internodes and roots that emerge from the tiller bases. Seminole roots may escape infection if seeds are placed deep to reach adequate moisture. Symptoms vary from dark brown to black internodes and roots for *C. sativa* and chocolate brown for *Fusarium* species. Economic losses result from reduced yields due to failure of the head to fill properly. Common root rot is estimated to reduce annual grain yields in the Great Plains by 5.7% (Cook and Veseth, 1991). Three *Fusarium* species are responsible for Fusarium root rot of wheat: *F. gaminearrum* and *F. avenaceum* dominate in the warmest wheat growing areas of the Great Plains, while *F. culmorum* dominates in the slightly cooler areas such as the northern Great Plains.

Root diseases favored by wet soils are: Take-all, caused by *Gaeumannomyces graminis* var. *tricici*; Rhyzoctonia root rot caused by several *Rhizoctonia* species; but mainly *R. solani*, and Pythium root rot caused by *Pythium* species. These species are not limited to areas of high precipitation. A wet spell of only a few weeks may be sufficient for infection to occur. The practice of leaving more crop residue on the surface to hold water and stabilize the soil against erosion may encourage more infection (Cook and Veseth, 1991). The best way to avoid these diseases is to include rotational crops that do not host the casual agents, or to include crops that decompose rapidly and limit the C source needed to survive.

Viral infections can cause many symptoms, but the most common symptom is stunted growth with shorter stems and reduced root growth. The important viruses in wheat are systemic and move from cell to cell throughout the plant. There are three viruses that can threaten spring and winter wheat, as well as other small grains and grasses in the northern Great Plains. Plants infected with barley yellow dwarf are commonly stunted and are usually yellow, but may also be red or purple. Barley yellow dwarf can be confused with N deficiency because of the similarity of symptoms. Four aphid species can be the vector for this virus. They obtain the virus when they extract sap from infected plants and transmit it as they feed on other plants. The primary aphid species associated with this disease in North America are: Bird cherry aphid (*Rhopolosiphum padili*); the English grain aphid (*Sitobion avenae*); the green bug aphid (*Schizaphis graminum*); and occasionally the rose grass aphid (*Metropolophium dirhodum*). Although corn can be infected, it seldom shows symptoms of the disease. However, it can be a major source of inoculum, and facilitate infection of nearby susceptible crops.

Wheat streak mosaic, a virus vectored by the wheat curl mite, is an important economic threat in the Great Plains. Although some wheat varieties tolerate this virus, none are completely resistant. Control requires the elimination of mite-infected volunteer grain and crops. Two to 3 yr between wheat crops are required to eliminate all infected volunteer plants (Cook and Veseth, 1991).

Soil-borne wheat mosaic occurs east of the Rocky Mountains. This disease occurs almost exclusively in winter wheat because the fungus vector (*Polymyxa graminis*) is aquatic-loving and infections occur in late fall when the soil is cool and wet. The symptoms are yellowing of leaves in low wet areas of the field in the spring. Close inspection reveals a light green and yellow mosaic pattern in the leaves and general stunting of the plant. The plant will appear to recover by heading, but the damage has already occurred as fewer and smaller heads will form. The fungus that transmits this disease is soil borne; therefore, the best way to control this disease is cleaning machinery before entering a new field and reducing inoculum levels by including crops in the rotation that do not support the virus. Also, there are resistant varieties of wheat available (Cook and Veseth, 1991).

In general, pathogens that affect cereal grains do not pose a problem in broadleaf crops. Therefore, rotating pulse and oilseed crops with small grains can be an effective means of managing disease, although it cannot be regarded as a catchall technique to disease prevention (Kaminski et al., 1997).

PULSE CROPS

Many pulse crops such as lentil, field pea, chickpea (*Cicer arietinum* L.) and faba-bean (*Vicia faba* L.) are susceptible to a fungus known as "ascochyta blight." Each crop is affected by a different species within the genus *Ascochyta*. If rain showers are frequent and/or prolonged, development and spread of the disease can be quick with crop losses approaching 50% or higher. This disease, caused by *A. rabiei*, has been so aggressive in chickpea in Saskatchewan that it poses a major obstacle for increasing the number of acres planted to this crop (Anonymous, 1996). The best means of control is to prevent inoculum from being established or becoming prevalent, which includes using crop rotation (not growing the same crop within a 3 to 5 yr span depending on type of pulse crop), planting disease-free seed, and use of resistant varieties. Separation of fields planted to the same crop from year to year is also recommended. Although helpful, these methods do not guarantee that disease will not occur if weather patterns favor its establishment. If symptoms do arise, a program of two or three applications of an appropriate fungicide at timely intervals will lessen crop yield losses. Incorporation of pulse crop residues may help in burying spores and hastening decomposition of infected plant material.

Anthracnose is a fungus in lentils that produce microsclerotia under wet, warm conditions. These are readily dispersed by wind during harvest, but do not survive for long periods when buried. Multiple races make host resistance difficult to achieve. Thus, the best strategy is to use crop rotations. Fungicides are effective when the disease pressure is low to moderate, but ineffective at high levels (Krupinsky et al., 2002).

Mycosphaerella blight caused by *M. poinodes* is the most important disease of field pea. It causes severe root rot in young seedlings and spreads on leaves and stems during warm moist conditions (Krupinsky et al., 2002). Survival of the pathogen is short lived in buried residue, but crop rotations and tillage are not very effective control measures because the disease is rapidly spread by airborne inoculum from adjacent fields. The pathogen population is genetically diverse and breeding programs for resistance is slow. However, selecting varieties with the most resistance is the best control mechanism. Foliar application of fungicides can also reduce disease severity (Krupinsky et al., 2002).

OILSEED CROPS

Sclerotinia diseases of oil seed and some pulse crops caused by *S. sclerotiorum* have the potential to cause substantial yield losses, but epidemics are sporadic (Krupinsky et al., 2002). However, the risk of sclerotinia disease has increased with the increased use of dicot crops in traditional cereal-producing areas because both oilseed and pulse crops are hosts to the disease. Of the oilseed crops, sunflower is the most susceptible. Management strategies include crop rotation, field sanitation, and foliar-applied fungicides. Crops rotation and field sanitation are of limited effectiveness because sclerotia of *S. sclerotiorum* survives well even when incorporated into the soil, and ascospores are wind borne over a wide area. Host resistance has been difficult to achieve. The best control in canola has been field scouting and applying fungicides at flowering if the disease is present at economic levels to warrant the expense of applying a fungicide (Krupinsky et al., 2002).

Insects

Insect pests can take a heavy toll on crop yield and quality. In wheat, several boring and chewing insect pests have a major effect during jointing and heading, and can cause the premature death of tillers, resulting in whiteheads. These pests infest the plant early in the spring, or in the case of winter wheat, infestation can occur in the fall.

Wheat stem sawfly causes extensive damage to wheat in the northern Great Plains, with damages estimated at $30 million annually in Montana alone, and $100 million area wide (T. Shanower, USDA-ARS, Sidney, MT, personal communication, 2002). The practice of strip cropping with wheat and fallow has fostered this insect pest, since host plants remain nearby perpetually. Wheat stem sawfly gets its name from the saw-like ovipositor that is used to insert eggs into stems of host plants. Mature larvae cut circular notches around the inside perimeter of lower stem regions, and plants usually lodge before harvest. Pupation occurs in the spring, and adult sawfly emergence occurs in mid- or late June and continues for several weeks (Philip and Mengersen, 1989; Morrill and Kushnak, 1996). Infested plants have lower head weight and lodged stems are difficult to harvest. Various methods of control are used; however, insecticides are not effective for sawfly control. Although deep tillage in the fall has been effective, the soil is then more likely to be eroded by wind and water. Solid-stemmed wheat cultivars are partially resistant to larvae, but they have comparatively lower yield potentials. Late-planted spring wheat commonly avoids attack, but has a reduced yield potential due to delayed seeding. Including nonhost crops such as oat or broadleaf crops in crop rotation is beneficial in some areas. Native parisitoids are increasing in importance for sawfly suppression (Morrill et al., 1998) and can be enhanced by reducing tillage (Runyon, 2001). Sawfly populations increase annually by 10-fold, therefore applied management practices must kill more than 90% of the individuals before subsequent populations are affected.

Hessian fly (*Mayetiola destructor*) occurs on both spring and winter wheat throughout much of the USA including the northern Great Plains. It causes tillers to stop growing, kernels to stop filling or stems to lodge. Damage is greatest in early seeded winter wheat and late seeded spring wheat, and when either is seeded into heavy wheat residue (Cook and Veseth, 1991). Hessian flies are intermittent pests in the Great Plains, but may become more serious if wet conditions prevail.

Planting winter wheat after mid-September is recommended (Philip and Mengersen, 1989).

Orange wheat blossom midge is a recent pest to the northern Great Plains and Canadian Prairies. Adults emerge in mid-June to mid-July; about the time wheat heads emerge. They lay eggs in the wheat head, which hatch in 5 to 7 d. The larvae move to the developing kernel where they feed for 2 to 3 wk. Mature larvae remain in the wheat head, each enclosed in a transparent skin until activated by rain. They then emerge and drop to the soil surface where they burrow into the ground to form overwintering cocoons. If the soil is moist enough, they emerge in the spring to start the cycle over again. If the soil is too dry, the larvae may remain in the cocoon to emerge in subsequent years. Control methods include rotations with nonhost crops such as pea, canola, or sunflower (Philip and Mengersen, 1989).

Various species of grain aphids are also pests of economic importance (Philip and Mengersen, 1989). They spend the winter as eggs on a host plant. Wingless females hatch in the spring and in about 3-wk give birth to live female young. These may become winged or remain wingless. These second-generation females will begin giving birth to young in about 2-wk. This process will be repeated every 20 to 30 d for the rest of the summer. When the days become shorter, males will be produced and egg laying will occur. Northern winters are too harsh for survival of most species; therefore most economic damage comes from aphids that migrate north. Aphids survive by sucking plant juices, robbing the plant of important nutrients. The pests also carry and transmit barley yellow dwarf virus, which can reduce wheat, barley, and oat yields. Chemicals can be used for control of aphids, but may not be economical. Alternative methods are to delay seeding of winter wheat, and to maintain crop residues on the soil surface, which increases short wave reflectance and helps repel the aphids (Cook and Veseth, 1991).

Sunflower beetle (*Zygogramma exclamationis*) is a native pest of sunflower that closely resembles the Colorado potato beetle (*Leptinotursa decemfineuta* Say). They overwinter as adults in the soil and emerge in the spring about the time that sunflower seedlings appear. They feed on the foliage, and can completely defoliate plants under severe infestation. Adults lay eggs over a 6-wk period. Eggs hatch in about a week and the young feed on the foliage at night and hide during the day. When mature, the larvae enter the soil and pupate in earthen cells. The pupal stage lasts about 2 wk. Adults from the new generation emerge and feed in August and early September before reentering the soil to overwinter. Natural control agents such as ladybird beetles [*Harmonia octomaculata* (F.)] and lacewings [Neuroptera: Chrysopidae *Chrysoperla plorabunda* (Fitch)] generally keep them below economical control levels. If not, chemical control methods are available.

Sunflower midge (*Contarinia schultzi* Gragne) is a small tan-colored insect that is found primarily in the Red River Valley of North Dakota. They overwinter in the soil as a cocooned larva. Adults emerge in early July when females lay their eggs on the bracts of the sunflower buds. The emerging larvae migrate to the base of the seed. Maturing larvae move out of the seed and drop to the ground for overwintering. Damage can range from complete destruction of all seeds to minor damage of the bracts alone. Destruction of seeds results in a cupped seed head. Chemical control is not effective. Crop rotations and avoiding planting next to fields infested the previous year are the best methods of avoiding economic damage. (Philip and Mengersen, 1989)

Alberta Agriculture, Food and Rural Development (2002) list bertha armyworm (*Mamestra configurata*) as the most significant pest of canola in Canada. It is native to North America, and occurs throughout the canola-growing regions. Natural regulators, such as climate, parasites, and predators, usually keep the populations low. When these fail, outbreaks can be dramatic causing widespread damage of broadleaf crops. However, chemical control can be achieved if detected early. Damage is done by the larvae, but detection can be achieved by monitoring adult male moth populations with pheromone-baited traps in mid-June through July to estimate the damage that will occur in July and August.

Various species of lygus bugs are found in the northern Great Plains and Canadian Prairies. However, *Lygus ineolaris* (Palisot de Beauvios) feeds on a host of crops grown in the region and can cause economic damage to crops grown for seed. They suck juices from the plants and their toxic saliva can cause flower buds and seedpods to drop. These pests have been a problem in alfalfa grown for seed and also in canola. (Philip and Mengersen, 1989). Lygus bugs spend the winter as adults under plant litter. In the spring they mate and move to crops for feeding and egg laying. Development from egg to adult takes about 45 d. Hot dry weather favors the build-up of lygus bugs. There are two generations per year in the southern prairies, but only one generation per year in the northern prairies. Lygus bugs can be controlled with one chemical application per generation.

There are about 600 species of grasshoppers in the USA and Canada. Five of these cause most of the damage to crops. These are: the migratory grasshopper, *Melanoplus Sanguinipes* (Fabricius); the differential grasshopper, *M. differentialis* (Thomas); the two striped grasshopper, *M bivittatus* (Say); the clearwinged grasshopper, *Camnula pellucida* (Scudder); and the bigheaded grasshopper, *Aulocara ellioti* (Thomas) (Morrill, 1995). Life stages are egg, nymph, and adult. The eggs from the species having the most potential for crop damage overwinter in the soil. Embryo development begins in the spring, and nymphs emerge over a period of several weeks. Cool weather may delay emergence. Newly emerged nymphs feed on succulent plants. They reach adult stage in about 35 to 50 d. Adults are sexually mature, and each female will lay up to 400 eggs over a 3-mo period. Populations build up over a period of years with successively early warm spring temperatures and moderate moisture conditions. Favorable conditions may lead to outbreaks at irregular intervals.

Damage to crops by grasshoppers usually results as populations increase in rangeland and then migrate to cropland. Heavy infestations have occurred during periods of drought in the northern Great Plains. Damage to plants can be from defoliation, head damage, and from lodging due to weakened stems. Yield losses can be expected if egg pod densities exceed 10 per square meter in cropland or 25 per square meter in borders, or with nymph infestations of 12 to 25 per square meter (Morrill 1995). Biological control agents include *Entomophthora gryli* (Fresenius) and *Beauveria bassiana* (Balsamo). These pathogens are favored by warm humid conditions. Spores from these fungi are spread by wind, and the grasshoppers are infected by contact. Bait formulation of microsporidian, *Nosema locustae* Canning, is available commercially. It is slow acting and should be applied after nymphs emerge, but before the adult stage is reached. Chemicals are available for grasshopper control, but are sometimes restricted in environmentally sensitive areas.

LAND CONVERSION

In the early 1960s, irrigation on the Great Plains expanded rapidly due in large part to the development of center pivot irrigation systems. These systems did not require the land leveling needed for flood or furrow irrigation, labor requirements were greatly reduced, and they were a cost effective way to reduce the risk of crop failure due to droughts. From 1990 to 1996 there was a net increase in land under irrigation in the northern Great Plains. Since 1996, there has been a decline in the amount of land under irrigation (Fig. 9–13) (Anonymous, 2001). The cause of this decline is likely a combination of dropping water tables, higher energy costs, and decreasing prices for the commodity crops that make up a substantial amount of the irrigated crops in the region. Environmental concerns, such as water quality, may have also contributed to the decrease in irrigation in some locations. However, there are areas of expansion. For instance, there has been an increase in irrigation along the upper Missouri River in Montana and North Dakota. About 200 000 hectares of land has been identified for potential

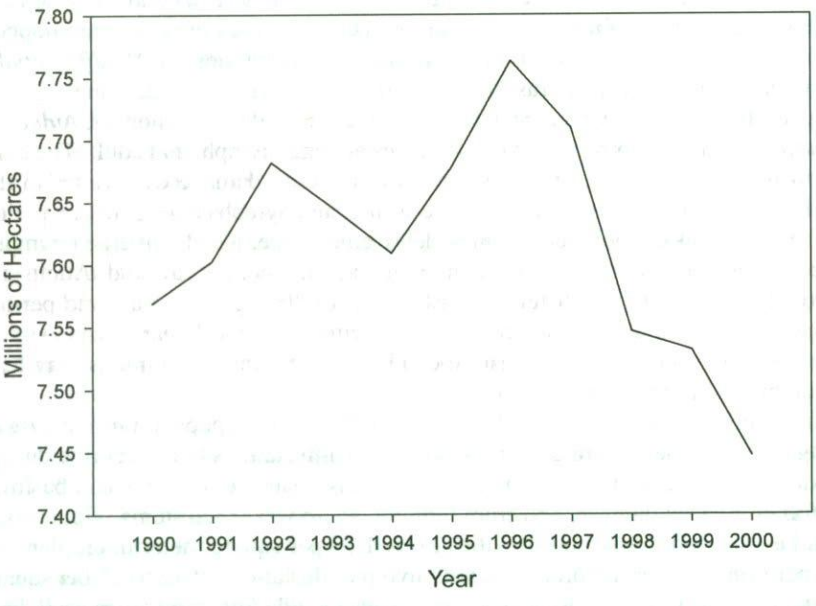

Fig. 9–13. Changes in irrigated lands in the northern Great Plains states from 1990 to 2000. (from Irrigation J. Jan 2001). Available at http://www.greenmediaonline.com/ij/2001/0201/images/0201srv.pdf (verified 1 Dec. 2005).

expansion of irrigation. This expansion will depend on many factors such as: environmental concerns, energy costs, and finding a market for high value crops that are needed to make it cost effective to invest in irrigations systems.

Mills (1994) estimated that northwestern Canada and Alaska have more than 55 million hectares of Class 1 to 5 agricultural land that has a similar precipitation amount and pattern as much of the northern Great Plains and Canadian Prairies. Of this, about 39 million hectares currently have a suitable climate for crop production. Using General Circulation Models, Mills (1994) estimated that an increase in atmospheric CO_2 to twice the current level would warm the area such that 55.3 million hectares of land would have soils and climate favorable for growing agricultural crops. Currently, agricultural development in northern Canada and Alaska is limited to a few enclaves along the Alaska Highway in Canada, the Matanuska Valley north of Anchorage, AK, and in interior Alaska near Delta Junction.

Recent studies have shown that interior Alaska has had a 25% increase in cumulative growing degree days (5°C base) since 1945 (Cochran and Sparrow, 1998), and the growing season has also increased by about 2 wk (Juday et al., 1997). This warming trend has reduced the risk of early frost killing crops before they are mature enough to harvest. Continued warming will lengthen the growing season and add more heat units so that crops that are not currently adapted to these northern climates can be grown. Agricultural expansion in northwestern Canada and Alaska has been slow in spite of the large amount of land available. Increases in Alaska's agricultural output have not kept pace with the increase in population growth (Lewis, 1998). However, the amount of cultivated land in the Yukon Territories of Canada increased fourfold during the decade between 1986 and 1996 (Hill, 1998).

Conservation Problems and Practices

Although cropping practices have changed immensely since the "dust bowl days" of the 1930s, erosion from wind or water runoff is still a concern for all of the northern Great Plains and the Canadian Prairies. Tillage and planting practices have been developed to leave crop residues on the soil surface to protect the soil by reducing wind and water velocity across the soil surface. These practices include: planting wind breaks, planting grass row barriers, strip cropping, contour farming, reduced tillage, and no-tillage. During years of normal precipitation and during normal windstorms or water runoff events these practices have worked quite well at holding erosion to tolerable levels. However, extended periods of drought reduce plant growth and can make it difficult to maintain adequate cover even with the best of minimum or no-till practices. Severe water runoff from thunderstorms and rapid snowmelt can still remove a considerable amount of valuable topsoil.

Direct seeding into existing crop residues has improved soil water storage and made it possible to annual crop in areas previously thought to be too arid for annual cropping (Aase and Reitz, 1989; Peterson et al., 1996). As a result, there is less summer fallow and more crop residue returned to the soil. Crop rotations that include pulses or oilseed crops are becoming more popular because they reduce the risk of soil-borne diseases, allow for alternative methods of controlling weeds, and, in the case of legumes, they reduce the amount of N fertilizer required per unit of production. Often these alternative crops do not leave as much crop residue as wheat or barley, or the crop residues decompose at a faster rate leaving less ground cover to protect the soil from erosion. Once topsoil is lost, additional fertilizer inputs are required to maintain crop yields (Tanaka and Aase, 1989) and recovery can be a very slow process in semiarid climates due to the low amount of vegetation produced.

Economics and Sociology of the Northern Great Plains

The economics of a farming system depends on climatic factors that limit the type of crops that can be grown (precipitation, growing degree days, and length of growing season), the price of these crops, availabilities of markets, and the cost of management practices needed to grow the crops. The distances to markets have always been a significant cost of farming in the Great Plains, which depend heavily on truck and/or rail for transporting crops to markets. Advances in farm machinery design (larger and more efficient equipment) and the shift to reduced- and no-tillage practices have allowed farmers to increase the amount of land they farm without increasing the workforce. This has led to static or declining populations in much of rural Canadian Prairies and the northern Great Plains.

Canadian Prairies

Climatic factors have greatly influenced the economics of farming. For instance, a summer fallow–cereal crop rotation has been and remains the predominant crop rotation in the Brown soil zone, which has an annual water deficit of nearly 400 mm; whereas, the summer fallow–cereal rotation has been largely replaced by diverse crop rotations that include cereals, oil seed, and pulse crops in the Black and Gray soil zones, which have an annual water deficit of <200 mm. Fallow has steadily declined since the 1970s. The greater crop intensity and higher crop yields of the Black and Gray soil zones translate into much greater net returns per hectare (Zentner et al., 2002).

An economic analysis by Zentner et al. (1996) and McConkey et al. (1996) of a long-term study comparing conventional tillage, conservation tillage and no-tillage on sandy loam, silt loam, and clay soils using a fallow-wheat or wheat-wheat rotation in the Brown soil zone found no difference in production cost between sandy loam, silt loam or a clay soil. The savings in labor, fuel, oil, machinery repairs, and machinery overhead with no-till was offset by additional herbicide costs. Yield increases due to the additional available water with no-till was only realized on sandy loam soils; thus, there was no economic advantage of using no-till on the silt loam and clay soils. Continuous wheat faired poorly in comparison to fallow-wheat rotation in sandy loam with all tillage practices, but had the highest net return on silt loam and clay soils. A later study, (Zentner et al., 2000) found that net returns can be improved by replacing fallow with a low water use legume such as chickpea or lentils, or using a 3-yr rotation of fallow-legume- wheat. There is also the added benefit of lower N fertilizer inputs with legumes in the rotation. However, growing high water use crops back to back in rotation, such as wheat-wheat or wheat-sunflower, has resulted in a negative net return on sandy loam.

The decision to use or not use fallow depends on the risk level one is willing to take and the opportunity cost of fallowing the land. The opportunity cost is a function of crop price, yield, and the cost of production. The cost of fallowing the land must also be considered (Zentner et al., 2002). The cost of controlling weeds in fallow requires more inputs in the form of tillage or chemicals in higher rainfall areas than areas with low rainfall, and the opportunity costs of fallow are greater in the high rainfall areas due to greater yields; thus, there is less incentive to include fallow in crop rotations. In the Dark Brown soil zone (intermediate water stress to Brown soil and Black soil zones), Zentner et al. (2002) calculated that average net returns were higher for a wheat–lentil rotation than for fallow–wheat or fallow–wheat–wheat rotations if the price ratio of lentils to wheat was >1.9. For substituting flax in place of fallow or wheat in a continuous wheat rotation the ratio was >2.4, and for canola it was 1.8.

In the Thin Black soil zone, the best net return was from a cereal–oilseed–pulse rotation, followed by cereal-oilseed, with the lowest being a monoculture cereal rotation. No-till and medium tillage systems had higher net returns than conventional tillage due to a 10 to 20% yield increase (Zentner et al., 2002). However they report mixed results in the cooler and wetter soils of the Gray soil zone. At Tisdale, conventional tillage had the best net return. In contrast, at Beaverlodge, net returns were highest with no-till, intermediate with medium tillage and lowest with conventional tillage.

Business risk involves yield risk, market risk, or both. Yield risk is influenced by weather events such as the time and amount of precipitation, severity of crop pests, effect of crop management on soil and water conservation, etc. Market risk originates from shifts in prices, capital purchases, changes in government policy, and international events and agreements (Zentner et al., 2002). Growers are faced with both long-term and short-term management decisions that affect the overall risk of doing business. Adoption of conservation practices is important for sustaining productivity, but may have to be tempered to meet short-term economic needs. Also, the decline in crop production due to loss of topsoil may go unnoticed for several years because of technological improvement, new varieties, and use of agricultural chemicals. Furthermore the effect of topsoil loss on crop production is not linear. As the amount of topsoil lost increases, the loss in productivity for each increment soil loss increases in a curvilinear pattern (Walker et al., 1987). The short-term effects of conservation tillage on net return have been mixed. On the positive side, conservation tillage has been found to increase yields due to better soil water relationships. This is particularly important during years with above normal temperatures and below normal precipitation (Zentner et al., 2002). Direct seeding into stubble improves the microclimate for plants by maintaining higher soil water content and reducing wind damage to seedlings (Cutforth and McConkey, 1997). There is also the added benefit of reduced labor and more timely seeding operations. However, there are reports of decreased crop quality, which may reduce market value; and increased pesticide costs can increase overall operating costs (McConkey et al., 1996).

Diversifying crop rotations can reduce risk provided the rotation contains crops with different requirements for water, disease cycles are interrupted, weed control strategies differ, and there is a difference in nutrient requirements. It also helped to include crops with product price variability that is independent of each other, so that some crops maintain their value during years of low prices for others (Zentner et al., 2002). Traditionally, conventional tilled summer fallow in a 2- or 3-yr rotation with cereals have been the main method of reducing risk in the drier soils of the Brown soils zone because of lower production cost and low grain prices. However, in more moist areas diversified rotations in companion with conservation tillage practices are often reported to have the lowest risk (Zentner et al., 2002). A rotation, such as spring wheat-flax-winter wheat-field pea, is often used. If the price of wheat is expected to be high or field pea low, a cereal–oilseed crop rotation might be used (Zentner et al., 2002).

Participation in all risk crop insurance and safety net programs (such as Net Income Stabilization Act) has effectively reduced or otherwise helped manage risk (Zentner et al., 2002).

NORTHERN GREAT PLAINS

For many, images of the Dust Bowl of the 1930s and more recently the tenets of the Buffalo Commons[1] define dryland agriculture in both the northern and southern Great Plains. The efficacy of dryland cropping in the region is seen by some as a tribute to the hardy and innovative, and by others as a tribute to federal assistance. Whatever the impetus, the seven states (Montana, North Dakota, South Dakota, Wyoming, Colorado, Nebraska, and Kansas) defined in this chapter as the northern Great Plains contain 30% of all U.S. cropland (Table 9–4) and are a productive part of the U.S. agricultural sector as well as the regional economy. The northern Great Plains leads the USA in the production of wheat and beef (*Bos taurus*), and together these states produce a significant proportion of the total annual U.S. feed grain and minor oilseed crops.

Farm size, principal crops, and climate vary from east to west within the northern Great Plains and within a given state, but in general, large farms and low population density characterize the region today. According to the 1997 Census of Agriculture, (USDA, NASS, 1997) average farm size in the northern Great Plains is 671 ha (Table 9–4). The largest farms tend to be in the more arid areas where wheat and cattle dominate. Along the eastern border of the northern Great Plains, where rainfall is more plentiful and more corn and soybean are grown, farms tend to be smaller.

Above average profitability does not necessarily follow from above average farm size. While Kansas, North Dakota, Nebraska, South Dakota, and Montana rank in the top 10 in total cropland in the 1997 U.S. Census of Agriculture, only

[1]The layman's interpretation of the article written by the Popper's is that the Great Plains should become, or as a result of depopulation would become, a publicly held region returned to it's native grasslands, populated by bison and managed by native peoples. For more detail see Popper and Deborah (1987).

Table 9–4. Northern Great Plains farm characteristics.

	Average farm size†	Number of farms	Land in farms	Cropland
	ha		ha	
Colorado	476	15 399	13 216 860	4 252 500
Kansas	303	34 979	18 666 159	12 150 000
Montana	977	15 703	23 736 150	7 128 000
Nebraska	358	35 742	17 437 793	8 950 500
North Dakota	522	22 677	15 940 535	10 935 000
South Dakota	574	22 704	17 963 726	7 857 000
Wyoming	1495	5 583	13 805 920	1 215 000
USA	197	1 911 859	377 377 078	174 595 500

† Based on Land in Farms which includes cropland, woodland, and pasture. Source data: 1997 Census of Agriculture.

Nebraska and Kansas ranked in the top 10 in the market value of crops sold. The production of low value bulk commodities that often depend on export demand for up to half of their disposition, coupled with the agronomic and climatic conditions of the region explains much of the dichotomy between farm size and value of production.

Much of the rural economy of the northern Great Plains remains highly dependent on agriculture at a time when many other rural areas in the USA have become increasingly diverse (Gale, 2000; Rowley, 1998). Changes in production agriculture together with a lack of alternative economic opportunities have had a profound effect on the population of the region. Plate 9–1 shows county level population changes between 1990 and 2000 according to the 2000 U.S. Census. Of the seven northern Great Plains states, only Colorado experienced growth at or above the U.S. national average. There is a striking correspondence between the low rainfall areas in Fig. 9–1 and the counties experiencing population losses in Plate 9–1.

Demographics of the Northern Great Plains

The Homestead Act of 1862 was designed to populate and cultivate the Great Plains in an agrarian manner with small towns and self-sufficient family farms. Much of the available land had been claimed by 1890, although agricultural settlement in the Great Plains continued into the 1920s. Farm numbers in the USA peaked in 1935 at 6.5 million and then began a downward trend that lasted through the middle 1990s, leveling off at about 2 million. As farm numbers fell, rural populations across the USA also fell as people began to migrate to urban centers in search of employment.

The population of the Great Plains as a whole has increased during the last 50 yr. However, on a state-by-state basis, growth has not been continuous and at the county level most of the growth has been in urban areas. Rathge and Highman (1998) found that 68% of Great Plains' counties had lower population in 1996 than in 1950. The states identified as having counties with the most persistent declines were North and South Dakota, northern Kansas, and northern Texas. The U.S. Census Bureau (2001) showed that North Dakota's population increased by only 0.5% between 1990 and 2000 with only 6 out of 53 counties gaining population (Plate 9–1).

During the last 20 yr there has been a slowing or reversal of population loss in many rural counties of the USA, as urban sprawl and congestion have renewed interest in smaller communities (Johnson, 1999). Rural counties increasing in population are primarily located within commuting distance of urban centers or areas with aesthetic qualities such as mountains, lakes, rivers, and pleasant climates. The trend holds true to a lesser extent in the northern Great Plains states in counties adjacent to urban centers and in counties where desired aesthetics exist. Since there are few urban centers and in many eyes, a decided lack of aesthetic qualities in the region, relatively few counties have benefited from this urban to rural migration. Ultimately, migration in the Great Plains is still mostly rural to urban, as it has been for many decades (Cromartie, 1998).

Population losses in the northern Great Plains are the result of negative net migration (out-migration greater than in-migration) and natural decrease (more deaths than births) as younger inhabitants move away in search of economic opportunity. Demographic studies find that the most consistent contributor to population loss in rural areas is a dependence on agriculture and mining (Harrington and Dubman, 1998; Rathge and Highman, 1998). In areas heavily dependent on farming, the trends and structural changes in agriculture have had a large impact on employment opportunities and as a result, on rural population and demographics. Farm and farm- related jobs in the USA have decreased more than 25% in just the last 25 yr. Between 1948 and 1996 employment in agriculture in the USA decreased by 5 million people while farm output increased at an average annual rate of 1.8% (Aheran et al., 1998). Most of the job loss and related population loss in rural areas is attributable to increased productivity in the agricultural sector as a result of technological change.

Productivity and Employment

Production agriculture has undergone continuous and tremendous technological change, particularly in the last 50 yr. In 1950 one farmer could feed 15 people; by 1970 one farmer could feed five times as many people. During those years, many of the technological changes that fueled the productivity increases in agriculture replaced labor with capital. Besides a decrease in the demand for agricultural labor, there was a decrease in number of farmers as farm size increased to spread the growing costs of production over larger acreage. Today, 25% of the farms in operation produce approximately 60% of the total value of U.S. agricultural production in a given year. The U.S. Bureau of Labor Statistics (2001) predicts the trend toward larger farms will continue through 2008 resulting in an 18% reduction in employment in production agriculture. The loss of agricultural jobs and farmers affects local retail and service industries, furthering the decline in employment opportunities and hastening the rural to urban migration.

Production agriculture has evolved into a highly competitive global industry that has benefited many and left some behind. During the 1990s many farm families have come to rely on off-farm income to maintain and enhance their standard of living. A growing number of farm operators do not list farming as their principal occupation. But in the northern Great Plains where off-farm employment opportunities are limited and wages are low, farming is the main occupation of most producers. Now, as in the past, many farms, especially in the northern Great Plains, depend on the federal farm program to survive periods of low commodity prices.

Farm Policy

Harrington and Dubman (1998) found that the Great Plains is the most agriculturally dependent region in the USA, and the most dependent on direct government payments to maintain farm income. The USDA's Economic Research Service recently concluded that farm program marketing loan benefits triggered by low crop prices from 1998–2000 reduced job losses in crop production and cut by half the negative effect of low prices on gross regional product in the northern Great Plains states.[2] (Vogel and Hanson, 2001).

From 1933 until 1996, income and price support policies were managed with a combination of acreage set aside programs, target prices and commodity loan programs. Deficiency payments were paid when the farm (market) price was less than a mandated target price. Participation in the farm program was linked to specific commodities and generally required producers to maintain base acreage in those commodities. Such programs include built-in incentives to produce the commodities covered by the program. Cereal grains were among the supported commodities and the northern Great Plains farmers, spurred by government support payments and technological change became specialists in production of these crops.

In addition to commodity support programs, a variety of conservation programs such as Soil Bank in the 1950s and 1960s, Sod and Swamp Buster in the 1980s, and the Conservation Reserve Program (CRP) in the 1990s were instituted to address issues of soil and water quality. The 1985 Food Security Act linked participation in farm programs to conservation efforts as concerns over agriculture's role in the environment grew. Before 1985, conservation and income support policies were not well coordinated and at times worked at cross-purposes. Many of these programs specifically targeted soil and water quality issues originating in the Great Plains. The CRP program, which idles highly erodible land in return for annual rental payments, has retired millions of acres of farmland in the northern Great Plains for the duration of the contracts, generally 10 to 15 yr. According to data released by the USDA Farm Service Agency (2000), 43% of national CRP acreage is in the northern Great Plains.

The 1985 and 1990 farm bills took the first steps in introducing changes that moved producers toward greater market orientation by lowering support prices and increasing planting flexibility. The Federal Agriculture Improvement and Reform (FAIR) Act of 1996, sometimes referred to as the Freedom to Farm bill, tied program payments to acreage rather than production of specific crops. Acreage enrolled in farm programs in any year from 1991 through 1995 was

[2]The northern Great Plains states include North Dakota, South Dakota, Nebraska, and Kansas according to the study.

eligible to enter a Production Flexibility Contract (PFC), which entitled the holder to a PFC payment. The PFC payments, lump sum payments that decline over the course of 7 yr (1996–2002), replaced deficiency payments. Target prices were abandoned, significantly reducing counter-cyclical income supports built into previous farm bills.

Acreage set asides were also totally eliminated and with program payments no longer tied to specific crops, producers were given the flexibility to base cropping decisions on market prices rather than maintaining participation in specific commodity programs. Since FAIR shifted commodity price risk from the Federal government to the commodity producer, crop insurance programs were expanded and subsidized as a means of risk management. In addition, marketing loan programs were established that in effect provide a floor price for commodities (the loan rate), albeit at lower rates than the former target prices. Marketing loan programs cover the traditional program commodities plus the oilseeds. The FAIR act also expanded the conservation reserve program to include cropped wetlands.

A great deal of optimism surrounded the passing of the 1996 Farm Bill. Commodity prices and export demand were strong over the course of the year or two before the new legislation and both farmers and policymakers were anxious to reduce or eliminate government's role in agriculture. In addition, in the global arena, many trade agreements called for the elimination of agricultural subsidies that were crop dependent or influenced production decisions.

Shortly after the passage of the 1996 farm bill, commodity prices began falling and export demand weakened in part due to the problems in Asian economies and in part due to record crop production worldwide. Figure 9–14 shows the index of prices paid by farmers has far out-paced the index of prices received by farmers in the past few years (USDA, ERS, 2001). Wheat, corn, and soybean prices fell by 20 to 30% (Fig. 9–15). In North Dakota cash receipts from the sale of wheat fell from nearly $1.5 billion in 1996 to $728 million in 1999, while

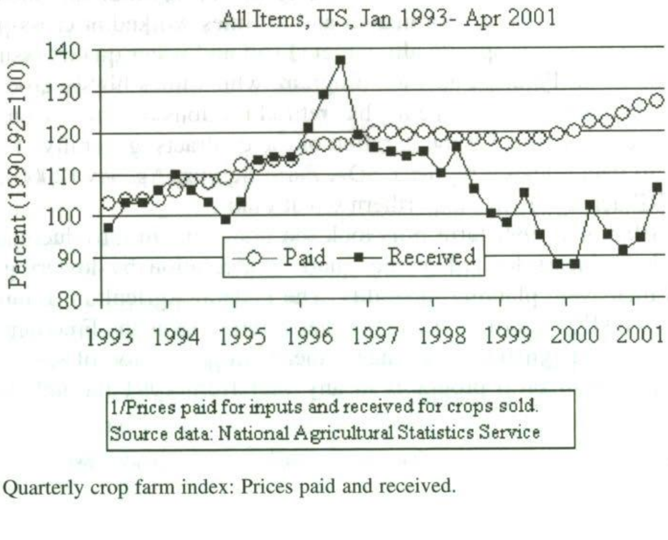

Fig. 9–14. Quarterly crop farm index: Prices paid and received.

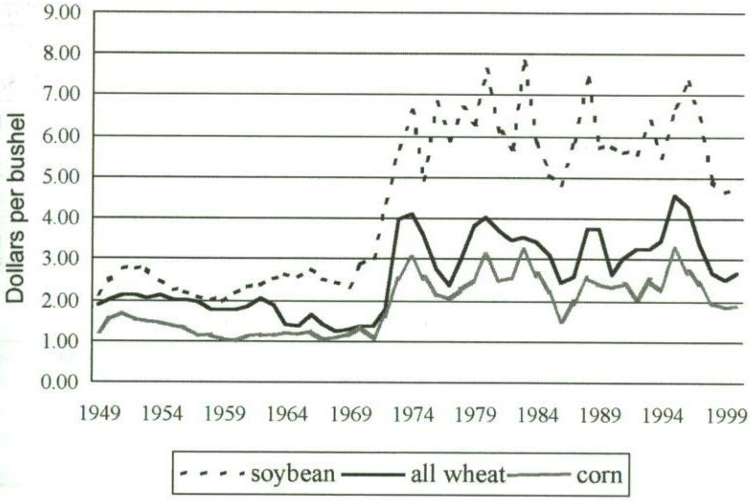

Fig. 9–15. U.S. soybean, all wheat, and corn prices, 1949–2000.

direct government payments[3] went from $353 million in 1996 to approximately $952 million in 1999 (North Dakota Agricultural Statistics Service, 2000). In many states nearly a third of gross revenue in 1998 and 1999 came from existing farm programs plus supplemental and disaster payments. Although the individual state figures for 2000 are not available at the time of this writing, similar results are expected. The Federal government paid $8.9 billion in emergency assistance in 2000 and $6.4 billion in loan deficiency payments, in addition to PFC and CRP payments (Morehart et al., 2001). Table 9–5 shows the importance of direct government payments to net farm income in the northern Great Plains in 1999.

Commodity prices increased somewhat in the 2000/2001 marketing year and are projected to increase further for the 2001/2002 crop. However, prices remain considerably below the expectations under which FAIR was drafted and export demand continues to lag. Many areas of the northern Great Plains have responded to the current round of low commodity prices by increasing crop diversity and cropping the land more intensively. Figure 9–16 shows that North Dakota farmers have decreased wheat and fallow acreage, and increased oilseed acreage since 1996. The increase in oilseed acreage reflects the desire for diversity to implement disease and weed control, but perhaps more importantly it is the result of favorable loan rate on oilseeds relative to other crops covered by the marketing loan program. Increases in oilseed acreage have been observed throughout the USA, a phenomenon that is not explained by strong oilseed prices. This demonstrates the difficulty of designing farm policy that does not create incentives to produce one crop over another.

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[3]Direct government payments include PFC payments, loan deficiency payments, conservation payments, and supplemental or emergency funding.

Table 9–5. Northern Great Plains net farm income and direct government payments in 1999.†

State	Direct government payments Dollars	Direct government payments U.S. Rank	Net farm income Dollars	Net farm income U.S. Rank
Colorado	368 005 000	20	922 905 000	17
Kansas	1 382 800 000	4	1 547 850 000	9
Montana	487 851 000	15	482 022 000	29
Nebraska	1 322 091 000	5	1 650 646 000	8
North Dakota	951 581 000	7	452 137 000	30
South Dakota	746 176 000	10	1 189 945 000	13
Wyoming	39 947 000	36	172 843 000	38
Total	5 298 451 000		6 418 348 000	
U.S. total	20 593 972 000		40 195 876 000	

† Data source: USDA/ERS, U.S. and state farm income database: net value added (with net farm

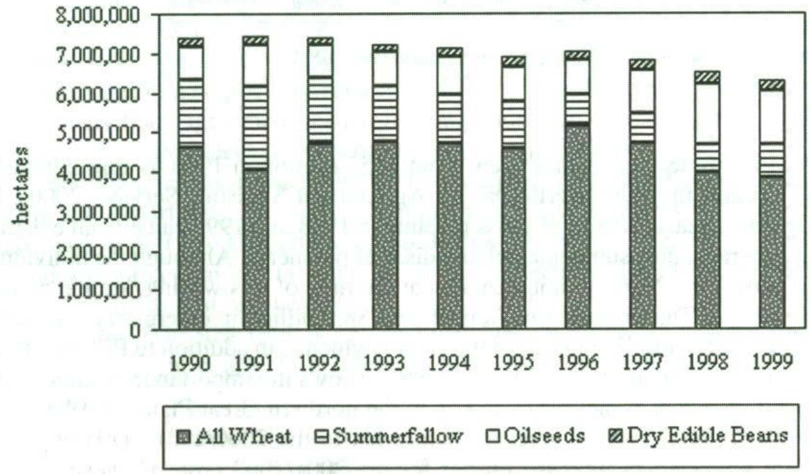

Fig. 9–16. Hectares of wheat, summer fallow, oilseeds and dry edible beans, North Dakota, 1990–1999).

The face of agriculture in the northern Great Plains has changed tremendously since its beginnings as an agrarian economy. Although out-migration and the rate of agricultural job loss have slowed in the last decade, the struggle to survive periods of low commodity prices and to support the existing population and infrastructure continues. Mechanical, biological and chemical innovations in production initially set the stage for specialization, or monoculture, in agriculture. Today's innovations are aimed at increasing diversity and improving conservation. The challenge to producers, scientists and policymakers is to create a sustainable profitable agricultural sector in the face of increasing global competitiveness and technological change without fostering reliance on government support.

NEED FOR RESEARCH

Soil Biology and Soil Physical Conditions

Observations of long-term research plots and farmer fields that have been direct seeded and with diverse crop rotations have shown distinct improvements in soil physical properties. The soil surface is often loose and friable with a mixture of partially decomposed plant residues ranging in size from barely visible to several millimeters in length. Growers report increased water infiltration and little surface crusting. They also report that the longer the fields have been direct seeded or no-tilled, the more rapid the disappearance of crop residues after harvest, and they are asking what effects these practices are having on the biology of the soil. However, this surface condition is not apparent at all no-till sites, indicating that soil type or differences in management practices are important in the development of this surface condition. Research is needed to determine how cropping practices (crop rotation, planting equipment, or preplant treatments) influence the biology of the soil, and how this is affecting soil structure, nutrient cycling, and plant health.

Carbon Sequestration in Soil

As mentioned in above sections of this chapter, past farming practices, such as a wheat–fallow rotation, have contributed to loss of SOM. Increased cropping intensity by converting from a conventional wheat–fallow rotation to continuous cropping offers a means to increase SOM, thus, acting as a long-term sink for atmospheric CO_2. This raises the possibility of producers receiving C-offset credits for adopting practices that store atmospheric C. However, not all crop rotations are equal. For instance, El Harris et al. (1983) found that a spring wheat–winter wheat rotation stored more C in the top 15 cm of soil over an 8-yr period than a winter wheat–pea rotation in the Pacific Northwest. They also found that there was a small increase in organic C with no-tillage compared to moldboard plowing, but no difference between no-till and sweep tillage. Aase and Pikul (1995) reported similar results from a long-term tillage/cropping study in eastern Montana. They found that, after 10 yr, a spring wheat–summer fallow rotation had less total organic C in the soil profile than continuous spring wheat. Thus, there is a need to conduct long-term tillage and crop rotation studies on a variety of soils and climates to determine which crop rotations store the most C and how important no-tillage practices are in storing C in the soil in any given area.

Management to Reduce Greenhouse Gas Emissions

Increasing cropping intensity and reducing tillage have both been shown to increase soil C storage. This may require greater use of commercial N fertilizer, which will likely increase nitrous oxide emissions, which is several times as effective at trapping heat as CO_2. Therefore, research is needed to determine crop rotations and tillage practices that minimize the need for N fertilizers. For example, pulse crops in the rotation reduce the overall amount of N fertilizer required. Green manures can replace all or part of the N requirement for subsequent crops but little is known about their effect on nitrous oxide emissions.

Alternate Crops

Considerable research effort is now aimed at finding alternate crops to grow in place of wheat or in place of fallow in a wheat–fallow rotation. However, wheat fallow is still practiced extensively in the northern Great Plains and the drier portions of the Brown and Dark Brown soil zones of the Canadian Prairies. This indicates that there is a need for additional crops, better varieties of existing crops, or better information on the advantages of crop diversification. Of course, there are bound to be disadvantages of crop diversification that need to be defined by research, also.

Interfacing Crop and Livestock Operations

Many operators in the northern Great Plains raise livestock as well as grow crops that are harvested and sold off the farm. This offers an opportunity to have a ready market for nontraditional crops that may not fit into a normal cereal production operation. For example, incorporation of a forage crop in place of fallow may enhance the overall farm operation by providing rotational benefits as well as supplying livestock feed. Questions concerning specific management options of such a system need to be answered to maximize crop and livestock productivity, and minimize degradation of the soil resource or the environment. Producers have the option of harvesting a forage and feeding it later, or grazing it in place. Research is needed to determine the best time to graze to avoid loss of stored soil water, loss of feed quality, and evaluate the effect of grazing on soil structure and water infiltration.

Climate Change

Short-term shifts in precipitation, humidity, and growing season temperatures have had a profound affect on harvested yields, crop diseases, and insect pressure, which have resulted in shifts in cultural practices. However, little is known about how long-term shifts in climate will affect crop yields, cultural practices, and adaptation of new crops.

Economics

Research that finds alternative methods of planting, harvesting, alternate crops, etc. will not be practiced by the producer unless it is profitable to do so. Therefore, it is paramount that economic studies be performed in close association with the research aimed at developing alternative cropping systems.

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